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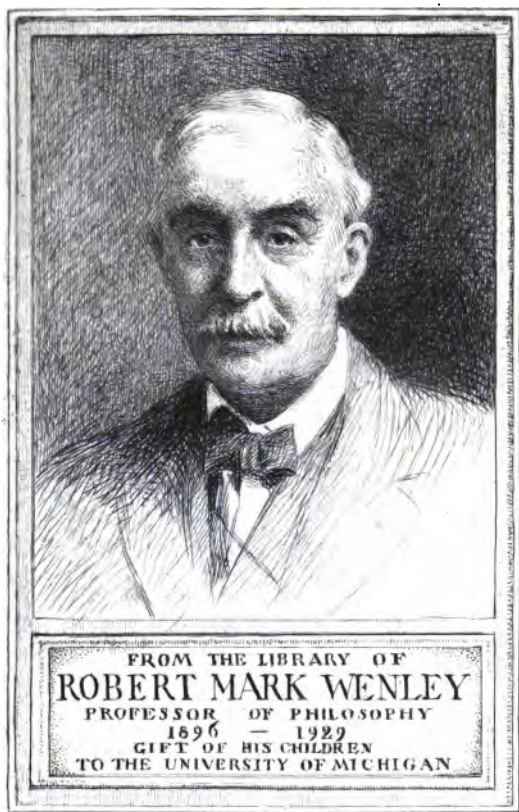
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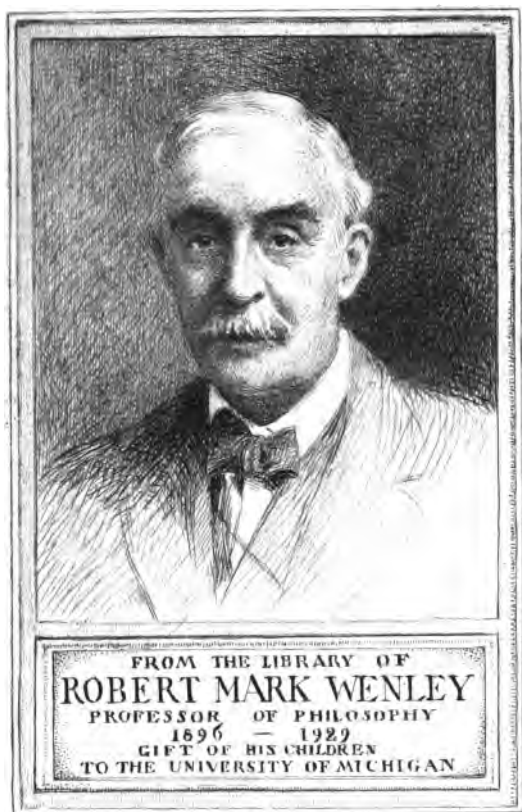
FELLOW AND PRÆLECTOR IN CHEMISTRY OF GONVILLE AND
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properly be looked for in an elementary text-book of chemistry, are omitted.

I have derived much assistance from the suggestive appendix, by Dr Armstrong, to the Report of the Committee appointed by the British Association to inquire into the teaching of Elementary Chemistry.

Various friends have read portions of the proofs : I have especially to thank Mr E. Edwards of Newcastle-on-Tyne, a man who has proved the worth of University Extension Lectures, for his kindness in reading all the proofs and for the many valuable suggestions he has given me.

M. M. PATTISON MUIR.

CAMBRIDGE, *June* 1893.

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THE CHEMISTRY OF FIRE.



CHAPTER I.

THE CHANGES THAT OCCUR WHEN A CANDLE BURNS.

MANY questions rise in the mind of a man as he gazes into a brightly burning fire. In this book I shall do what I can to disentangle, and put into definite expression, the questions which the fire suggests to the chemist ; to indicate the course which the chemist follows in trying to find answers to these questions ; to put before the reader some of the replies—partial though they be—which chemistry makes to the riddles read by the fireside ; and to set forth, with what clearness and grasp I can, the connexions which exist between the changes that proceed on the hearth, and changes that form part of the great economy of nature.

Read aright the story of the burning coal, or wood, or peat, and you have in your hand one of the many keys which must all be used in unlocking the secrets of the material universe. Fire is a common thing ; but in common things are to be found the solutions of the deeper things.

The mark or note of all chemical occurrences is change. As we look at the burning wood or coal, we see a slow process of change ; a change from a solid faggot or lump

of coal to smoke, flame, and ashes. Wherein does this process of change differ from other changes? Wherein, for instance, does it differ from the change which happens when a magnet is drawn over the surface of a piece of steel, and the steel acquires the property of attracting iron-filings? Into what is the wood or coal changed? Does the matter of the coal cease to exist? Is there a creation of new matter? Is anything concerned in the change besides the material that is burnt? Is the change that happens when coal burns like the change which happens when wood, or gas, or oil, or candle burns? If these changes are similar, wherein, precisely, does the similarity consist? How can we disentangle the parts of the change which begins with coal and ends with ashes? Why will not the ashes burn too? Where does the heat of the fire come from? Is it something that is locked up in the coal, and rushes forth when the gate is opened? If so, what is this gate? why is it closed in the coal? and what is the key which unlocks it? The burning fire supplies warmth and light; is, then, the great giver of heat and light—the sun—a vast fire? How is the sun fed with fuel, and why is it that his warmth is not lessened nor his light quenched?

These questions, and questions such as these, crowd on the mind of the chemist as he gazes into the fire. These questions cannot be answered by thinking only, but by doing, and thinking on the results of the doing. We begin by questioning; we seek answers to our questions by having recourse to experiments; we reason on the answers which the experiments give us; and then we devise fresh experiments to solve the new questions which are suggested by the partial answers we have received.

When a candle, an oil lamp, and a piece of wood are

CHANGES THAT OCCUR AS A CANDLE BURNS. 3

burnt, there appears to be a loss of matter in each case. The candle disappears, the oil slowly vanishes, nothing of the wood remains but a little heap of ashes. But because the candle, the oil, and the wood appear to be destroyed, it does not follow that they are destroyed. The senses alone are very fallible guides; to trust one sense, in the present case the sense of sight, without criticising its judgment, would be sure to lead us astray. If one hand is kept for some time in ice-cold water, and the other hand in hot water, and if both are then dipped into water at the ordinary temperature, this water feels warm to the hand which before had been in the ice-cold water, but it feels cold to the hand which before had been in the hot water. Did we trust to the uncorrected judgment of one hand we should pronounce the water to be warm; if we trusted to the evidence of the other hand we should say that the same water was cold. When a piece of sugar is put into a cup of tea or coffee the sugar seems to be destroyed; but although its presence cannot be recognised by the senses of sight and touch, it is sufficient to sip the tea or coffee to be convinced, by the evidence of taste, that the sugar still exists.

Perhaps, then, when the candle, the oil, or the bit of wood is burnt, something may be produced different from the things which are burnt. When the candle burns fairly and well, we see no new thing formed, we smell nothing, nor can we hear, or touch, or taste anything.

To prove that a colourless gas or air is formed when a candle burns.*

Experiment 1. — Let the candle be burnt in a large glass

** Always read the whole of the description given of an experiment before beginning to perform the experiment.*

jar with a wide mouth (Fig. 1); attach the candle to the end of a piece of stick, light it, lower it into the jar, and let it burn there for three or four minutes; then withdraw the candle, and pour some clear *lime-water* into the jar; when the jar is shaken the lime-water becomes turbid and filled with fine, white, solid particles. Now take another similar clean jar, pour some lime-water into it, and shake the jar; the lime-water remains clear and free from turbidity. Again light the candle, lower it into the second jar, let it burn for a few minutes, take it out, and shake the jar; the lime-water becomes filled with white solid particles.

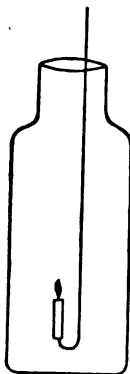


Fig. 1.

The conclusion to be drawn from these experiments is, that something is formed during the burning of the candle, that this something is a colourless air or gas, not distinguishable by the sight from common air, and that this air or gas has the property, which common air has not, of producing a finely divided solid substance when it is shaken with clear lime-water. Now perform the following experiment.

To prove that a colourless gas is formed when an oil-lamp, a piece of wood, or a gas-jet is burnt.

Experiment 2. — Burn a *small* oil-lamp for five or ten minutes in a large wide-mouthed jar of air, and then pour some clear lime-water into the jar and shake well; the lime-water becomes turbid. Repeat the experiment with a burning slip of wood; the result is the same as before. Repeat the experiment with a small jet of gas burning at the end of a glass tube drawn to a fine opening; the result is the same as before.

Hence it is probable that the same colourless gas or air is formed when an oil-lamp or a jet of gas burns, and also when a piece of wood burns, as is produced when a candle burns. It is important to notice that the results of the

experiments just described do not prove that the gases or airs produced in these three cases are identical; the gases all form white solids when they are shaken with lime-water, but there may be several gases which have this common property, and nevertheless are different in other respects. It must suffice here to say that careful examination has shown that all the properties of the gas that turns lime-water turbid and is formed when a candle burns are identical with all the properties of the gas that turns lime-water turbid and is formed when an oil-lamp, a jet of coal-gas, or a piece of wood is burnt.

But there may be something else besides a colourless gas produced when a candle, or an oil-lamp, or a gas-jet is burnt.

To prove that water is formed when a candle burns.

Experiment 3.—Arrange an apparatus as shown in Fig. 2.

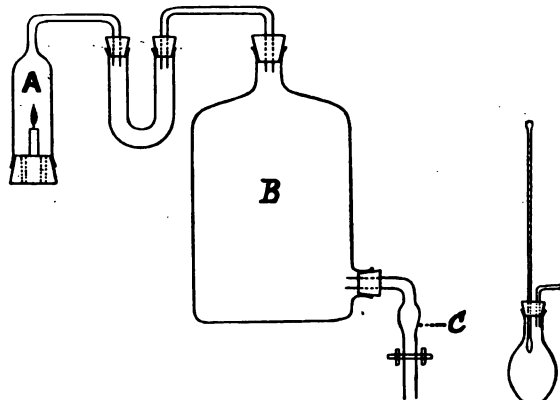


Fig. 2.

Fig. 3.

The tube A is about 7 to 8 in. (18 to 20 centims.) long, and about 2 in. (5 centims.) wide; the lower end carries a cork pierced with

several holes and having a small candle fixed in it. The tube A is narrowed at its upper end, and the narrow portion (about $\frac{1}{4}$ in. wide) is bent round, and passes through a cork which is fitted into a U tube about 3 ins. (7.5 centims.) long. The other limb of this U tube is connected by a glass tube with a large jar full of water, B, from which the water can be allowed to flow, by the tube C, slowly or rapidly as required. The greater part of the U tube is immersed in cold water. Light the candle and allow the water to flow from the jar at such a rate that a current of air is drawn through the apparatus rapidly enough to maintain the burning of the candle. Stop the burning after about 15 to 20 minutes, transfer the liquid which has collected in the U tube to a *very small* flask fitted with a cork carrying a thermometer and a piece of glass tubing bent at right angles (*see* Fig. 3). Heat the flask, by a Bunsen-lamp burning with a small flame, until the liquid boils, and note the reading of the thermometer. If the thermometer is graduated on Fahrenheit's scale, you see that it indicates 212° , and if graduated on the centigrade scale it indicates 100° , as the liquid boils. Also taste, smell, and look closely at the liquid; it has the prominent properties of water.

Now it is a characteristic property of water to boil (under the ordinary atmospheric pressure) at 212° F. or 100° C.; hence the liquid which has been formed by burning the candle in a current of air is water.

Repeat experiment 3,—but burn a *small* jet of coal-gas inside the lower end of the tube A. Water is again produced.

We have thus confirmed the supposition that when candle, oil, or coal-gas is burnt, something is produced different from the things that are burnt; and we have found that in the cases of a candle and coal-gas, at any rate, two different substances are produced. The gas which is formed when one of these combustible bodies is burnt is called *carbonic acid*; the other substance which appears during the burning is *water*.

CHANGES THAT OCCUR AS A CANDLE BURNS. 7

How unlike candle, oil, or coal-gas are the things which are formed when candle, oil, or coal-gas burns! Carbonic acid gas is colourless, tasteless, odourless; it will not burn, but it puts out flame; it is considerably heavier than air: the properties of water are well known—it is a colourless, odourless, almost tasteless liquid.

To make and examine the gas that is produced when a candle burns.

Experiment 4.—The student should, if possible, prepare some carbonic acid gas by adding muriatic acid to marble in small

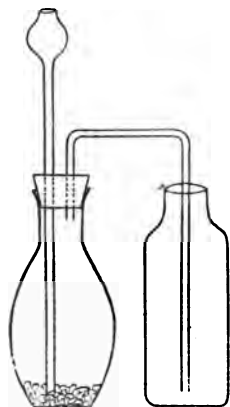


Fig. 4.

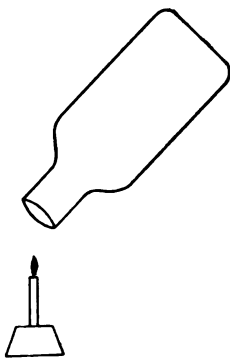


Fig. 5.

pieces in a flask fitted with a cork carrying tubes as shown in Fig. 4; the marble should be covered with water, and the acid then poured little by little down the funnel-tube. The gas which is produced should be collected in two dry bottles as shown in the fig; when a taper is extinguished as soon as it is placed in the mouth of the bottle, that bottle is filled with the gas. The gas should be smelt (taking care not to breathe much of it into the lungs), it should also be poured downwards on to a burning candle which will thus be extinguished (Fig. 5)—

hence the gas is heavier than air—and some of it should be shaken with lime-water. The student will thus be better able to contrast the properties of this gas with those of candle-stuff. It is assumed here that the gas produced as directed is carbonic acid.

Have we quite satisfactorily proved that these two substances, water and carbonic acid gas, are produced from the burning candle, coal-gas, or oil? Was there anything present during the experiments from which these substances might have been formed? We burnt our coal-gas, candle, or oil-lamp, in a glass jar which at the beginning of the burning was filled with air. Might the water and carbonic acid have come from the material of the jar, or from the air in the jar? Let us concentrate our attention on the case of the burning candle:—If the candle is changed, in some way we cannot as yet understand, into water and carbonic acid gas, and into these only, then the sum of the masses of these two ought to be equal to the mass of the candle burnt: in other words, a determinate quantity of candle ought to produce, when wholly burnt, such quantities of water and carbonic acid gas, that the sum of these two quantities is equal to the quantity of candle used.

The practical method of measuring mass or quantity of matter is to find the weight of the matter. If then we weigh a piece of candle, and burn this weighed piece in an arrangement such that the water and carbonic acid gas that are formed are caught and weighed, we shall have a means of finding whether the weight of these two is, or is not, equal to the weight of the candle burnt. It is not necessary to determine the actual weight of the candle, nor to burn it completely. The arrangement represented in Fig. 6 suffices for our purpose.

To prove that the things formed when a candle burns weigh more than the unburnt candle.

Experiment 5.—A large, moderately delicate balance is required. Two ordinary glass lamp-cylinders are procured, as nearly alike in size and weight as possible; each is fitted at its lower end with a cork carrying a little bit of candle, and one of these corks is pierced with several holes; at a little distance above the top of each candle is placed a piece of rather fine wire-gauze (*a, a* in Fig. 6), on this gauze is placed a quantity of stick caustic soda broken into pieces about half an inch long, and the soda is covered with another piece of gauze. *The soda should not be put into the cylinder until every other part of the experiment has been arranged and all is in readiness to begin the burning; the reason is that caustic soda rapidly absorbs various substances from*

the air. The cylinders are suspended by thin wire (not string, as this may catch fire) from the ends of the beam; the balance is brought into equilibrium by putting small shot into the pan on the side which at first is too light. The cork pierced with holes is now removed, the candle fitted into this cork is lighted, and

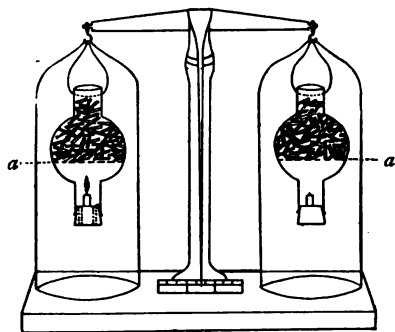


Fig. 6.

the cork is *at once* put back into its place in the cylinder. The candle burns, air being admitted through the holes in the cork; when the burning has proceeded for a little time, the end of the beam to which the burning candle is attached begins to sink; this goes on until it is very evident that the cylinder which contains the burning candle is becoming heavier.*

* Two cylinders similarly arranged are used so that the conditions may be alike at both ends of the beam, save that the candle suspended to one end is burnt, while the other is not.

How can the increase in weight be accounted for? The caustic soda in the cylinder will not allow either water-vapour or carbonic acid gas to pass through it; it retains these gases as a dry sponge retains water. Knowing this, we see that the experiment indicates that the sum of the weights of the water and carbonic acid formed during the burning of a candle is greater than the weight of the candle burnt. To complete the proof of this statement, it would be necessary to weigh carefully the glass cylinder before and after the experiment; if this were done, it would be found that the weight of the cylinder remained unchanged; hence the water and carbonic acid cannot have come from the glass vessel wherein the candle was burnt. But if the water and carbonic acid taken together weigh more than the candle did, and if these two substances are formed from the candle, something must be added to the candle during the process of burning. What can this something be, and from whence can it come? It is as if you weighed an apple, laid it down for a moment to attend to something else, came back and weighed the apple again, and found it weighed more than before; if this happened, you might reasonably suppose that some one had stuck a piece of lead, or a stone, or something of that kind, into the apple when your back was turned. Has something been added on to the burning candle? The only source from which this unknown something can have come seems to be the air. Is then the air concerned in the burning of a candle?

To prove that the air is concerned in the burning of a candle.

Experiment 6.—If you can procure an air-pump with a fair sized bell-jar receiver, you can find an answer to this question

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by placing a piece of lighted candle under the receiver, and pumping out the air; the flame of the candle grows feebler, and still more feeble, until at last the candle goes out. If you repeat the experiment, but just as the feeble flame is flickering to extinction you admit air, *in a gentle stream*, you will see the flame grow larger and the candle again burn vigorously.

If you have not an air-pump, you must content yourself with an extinguisher, which acts by cutting off the supply of air to the candle. A few simple experiments made with a burning candle and an extinguisher will convince any one who knows that the candle, like everything else, is surrounded by a sea of air, that a candle cannot burn without air, and that, therefore, if we wish to find where the products of the burning, water and carbonic acid, come from, we must give heed not only to the candle but also to the air which surrounds it while it is burning.

But we have not yet found out the part which the air plays in the burning of the candle. We can see the candle and touch it, we can watch it getting smaller as it burns; but we cannot see the air, nor have we any sense by which we can immediately trace the process whereby the burning candle and the air in which it burns conjointly produce water and carbonic acid. We want to find out whether the air that remains when the candle has burnt for some time differs from the original air. It has been stated that caustic soda absorbs and retains carbonic acid gas; if, then, a candle were burnt in a closed vessel full of air, and the carbonic acid formed were removed by means of caustic soda, we should be able to examine the air that then remained. Now if a lighted candle is brought into a jar of air, and the mouth of the jar is closed, the candle very soon goes out, because the carbonic acid that

is formed extinguishes the flame. Let us therefore burn, in a closed vessel, some substance which burns more rapidly and more energetically than a candle, and which does not produce carbonic acid while it is burning. The substance that is present in ordinary lucifer matches is the kind of thing we require : this substance is *phosphorus*.

To examine the burning of phosphorus in air.

Experiment 7.—Cut a little piece of phosphorus, dry it by gentle pressure between filter paper,* place it in a little cup on the end of a wire which passes through a plate of metal (*a deflagrating spoon*), set fire to the phosphorus, and plunge it into a dry wide-mouthed jar made of thin glass (the metal plate closes the mouth of the jar). The phosphorus burns very brightly and rapidly ; as the burning proceeds you notice a white snow-like solid forming on the sides and bottom of the dry jar. When the combustion is finished, and the jar has become cool, pour a little water into the jar and shake up ; the white solid rapidly disappears in the water.

When phosphorus is burnt in air, then, a solid substance is produced, and this solid is easily dissolved by water. Hence, when we burn phosphorus in an enclosed quantity of air it will be easy to get rid of at least one of the products of the burning, and so to examine the air which remains.

To burn phosphorus in an enclosed quantity of air and examine the air that remains when the burning is finished.

Experiment 8.—Remove the stopper from a fair sized bell-jar, and insert a good cork in place of the stopper ; let the

* Great care should be taken in handling phosphorus. It should be always kept under water. When a piece is required for use it ought to be cut off under water, and handled as little as possible, because phosphorus soon takes fire when exposed to air, especially if it is dry.

CHANGES THAT OCCUR AS A CANDLE BURNS. 13

cork be fitted with a short piece of rather wide glass tubing bent at right angles; to this attach a piece of caoutchouc tubing about a couple of feet long, and place a good pinch-cock over this tubing, as near as possible to the end of the glass tube which passes through the cork. Fix a small crucible or basin in a cork, place six or eight pieces of phosphorus, each as big as a pea, in the little crucible, and float the cork on the water in a dish six or eight inches deep; remove the cork from the bell-jar, and place the jar over the little dish floating on the water; set fire to the phosphorus by a hot iron wire passed down through the opening of the bell-jar, and *at once* insert the cork *firmly* into the mouth of the jar, the pinch-cock being

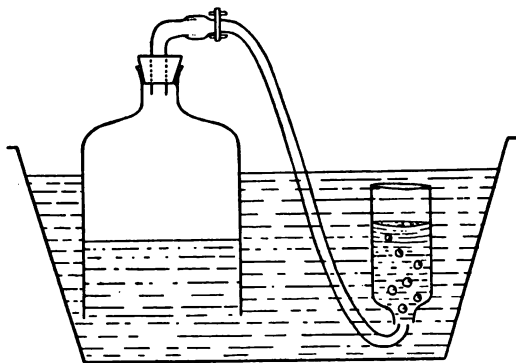


Fig. 7.

firmly closed. As the burning proceeds the water slowly rises in the bell-jar; hence the burning phosphorus is absorbing or withdrawing a portion of the air in the jar. When the phosphorus ceases to burn, move the bell-jar standing in the dish of water to a deep trough containing water; support the bell-jar in the water by a clamp, and remove the dish from under the bell-jar. Fill three rather small bottles with water, and place them mouth downwards in a dish containing water; slip a glass plate under the mouth of one of these bottles, and place it, full of water, in the large trough (the bottle may be

allowed to sink to the bottom of the trough, taking care that it is kept in a vertical position with its mouth downwards);* loosen the clamp that holds the bell-jar, and *slowly* depress the jar in the water, at the same time opening the pinch-cock; the air in the jar is thus forced out. Keep the open end of the caoutchouc tube under the water; allow a little of the air to escape, and then move one of the bottles you filled with water so that its mouth is over the end of the caoutchouc tube. The air which is being slowly forced out of the bell-jar rises into, and collects in, the bottle, from which the water is driven out into the trough (*see* Fig. 7). When the bottle is full of this air, slip a glass plate under its mouth, and remove it to the dish of water in which the other two bottles are standing. In the same way fill the other two bottles with the air in the bell-jar. Now place one of the bottles, mouth upwards, on the table, and bring into it a burning chip of wood, or a burning match; the burning match goes out. Pour a little clear lime-water into the second bottle; the lime-water remains clear when the bottle is shaken. Invert the third bottle at a little distance over a lighted candle, taking care that no drops of water trickle down on to the candle; the candle is not extinguished, hence this gas is not heavier than air (*compare* the results of a similar experiment made with carbonic acid gas; experiment 4, p. 7).

The results of this experiment show that as phosphorus burns in air it withdraws and absorbs a portion of the air, and that the air which remains is different from ordinary air inasmuch as it extinguishes the flame of a match; moreover, the air which remains differs from carbonic acid inasmuch as it is lighter than this gas and produces no turbidity when shaken with lime-water.

It is probable that the burning of a candle in air, like the burning of phosphorus, is accompanied by a withdrawal of a portion of the air. We are not in a position to prove or

* If a large trough is obtainable with a side-shelf just under the water, the three bottles may be filled with water in the trough and set, mouth downwards, on this side-shelf.

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disprove this supposition at present. We have found one reason why it is more difficult to examine the air left after a candle has burnt than to examine the air left after phosphorus has burnt (*see* pp. 11, 12). If the statement is accepted that the burning candle behaves towards air very similarly to the burning phosphorus, then, keeping this in mind, and putting together the results of the experiments now made, we are able to draw the conclusions that water and carbonic acid gas are obtained when a candle burns in air, that a portion of the air disappears as the candle burns, and that when the air which remains has been deprived of the carbonic acid gas produced in the process of burning the candle, what is then left differs from common air inasmuch as a taper will not burn in it, and differs from carbonic acid gas—in which also a burning taper goes out—inasmuch as it has no visible effect on clear lime-water.

It seems probable, then, that the burning candle seizes hold of, absorbs, combines with, or in some way becomes intimately united to, some portion or constituent of the air, thus producing water and carbonic acid gas, and that the portion or constituent of the air which remains is unlike ordinary air in its behaviour towards a burning body. But is air composed of more than one substance or kind of matter? Is candle-stuff composed of several things? To gain a further insight into the process we are studying, we must seek answers to the questions—What is the composition of air? What is the composition of candle-stuff? Of what are water and carbonic acid composed?

A cup of tea is composed of tea and water, it may be also milk and sugar; a pudding is composed of flour, butter, eggs, sugar, perhaps also currants, raisins, or spices.

The tea is not very different from the things of which it is made: the more sugar there is put into it the more does the taste of the sugar become evident; the less the quantity of milk added the deeper is the colour of the tea-infusion, and the less milky does the liquid look and taste. You cannot see the eggs in the pudding, nor is the butter visible, but you can tell the presence of these things by the effect they have on the goodness of the pudding. But sometimes you cannot determine the ingredients of a substance by looking at it, or by tasting or smelling it, or by touching it: you would not find out by inspection that ink is composed of green vitriol, water, tannin, and gum; unless you knew by experience, you would not suppose that flesh, bone, and muscle are composed of the substances which are consumed as food. You would not think it likely that sugar is composed of charcoal and water; but if you pour some hot oil of vitriol on to loaf-sugar in a tall jar, you will see clouds of steam coming off, and a mass of black charcoal will remain. You would never discover by looking at chalk, or by handling, tasting, or smelling it, that one of the components of this substance is carbonic acid gas.

To illustrate the change produced in whitening by heating it.

Experiment 9.—But if you place a little whitening—which is chalk in a state of very fine division—in a tube of *hard* glass, fitted with a cork carrying a glass tube bent twice at right angles, and heat the tube, at first gently and then to the highest temperature you can attain by means of a good Bunsen lamp, you will find that a gas is given off, and that if this gas is allowed to bubble through a little lime-water it produces a turbidity therein (*see* Fig. 8, next page).

It is evident that the properties of a substance may

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differ much from the properties of the substances of which it is composed.

We should not then be very much surprised to find that a candle is composed of substances quite unlike candle-stuff, or that air is composed of substances unlike air.

To obtain charcoal from a wax candle.

Experiment 10.—Let a wax candle be cut into pieces, let the pieces be placed in a tall jar, and let about a couple of ounces of oil of vitriol* be heated in a beaker (placed on wire gauze on a tripod), and then poured over the candle-clippings; after a short time steam begins to come off, the candle-stuff swells up and blackens, and soon a quantity of black porous charcoal remains in the jar.

Charcoal seems to be one of the constituents of a candle. This experiment does not prove that charcoal is a component of candle-stuff, because it is possible that the charcoal may have come from the oil of vitriol, or from the glass vessel. It would lead us too far afield to prove by experiment that neither oil of vitriol nor glass contains charcoal. At present you must be content to accept the statement that it has been proved that charcoal does not enter into the composition of either of these substances.

If charcoal is one constituent of candle-stuff, some other substance, or other substances, must also enter into the composition of the candle, because a candle is very different in appearance and texture from charcoal.† The results of

* The greatest care should be taken in handling oil of vitriol, especially when it is hot; if dropped on to the flesh, it burns very seriously.

† It is not quite correct to say that *charcoal* is a constituent of candle; *carbon* is a constituent of candle (see p. 42).

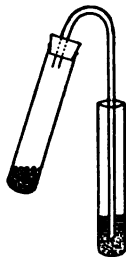


Fig. 8.

an experiment, which at first sight seems to have no bearing on the question of the composition of candle-stuff, make it probable that one of the constituents of this substance is a colourless, inodorous, very light, inflammable gas.

To pass an electric current through water mixed with oil of vitriol, and examine the gases so produced.

Experiment 11.—For this experiment a galvanic battery of three or four cells, or a fair-sized secondary cell (accumulator), is required. Attach a copper wire to each pole of the battery, or secondary cell; around the other end of each wire twist a piece of platinum wire, and to this attach a piece of thin platinum foil about two inches (or five centimetres) long and one inch broad; * arrange these pieces of platinum as shown in Fig. 9, letting the platinum wires pass down the sides, and a little way along the bottom, of a flat dish, and turning the pieces of foil upwards, as shown; take care that the junctions of the platinum and copper wires (*see footnote*) are outside the dish. Now pour into the dish sufficient water, previously mixed with about $\frac{1}{20}$ of its volume of oil of vitriol, to cover and extend a little way above the pieces of platinum foil. Fill three test tubes with water, mixed with about $\frac{1}{20}$ of its volume of oil of vitriol, and place them, mouth downwards, in the dish; while this is being done, bubbles of gas form on the surface of each piece of platinum, and then escape into the air. Now move a test tube (full of acidulated water) over each piece of platinum foil (*see Fig. 9*), and support it there by a clamp. The gas coming off from each

* Small pieces of platinum wire may be attached to the foil by placing the wire on the foil, so that the wire extends about $\frac{1}{2}$ an inch down the centre of the foil, heating the foil and wire to bright redness over a Bunsen-lamp, placing them on a hard surface (such as a piece of iron) and vigorously and rapidly hammering the wire and foil together; by repeating this treatment once or twice a good junction is effected. The platinum wire may then be twisted round the end of the copper wire.

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piece of platinum collects in the test tube placed over the platinum. You notice that one tube becomes filled with gas about twice as rapidly as the other. When one tube is filled with gas, and the other is about half filled, place the thumb under the mouth of the tube that is full of gas, undo the clamp, lift the tube out of the dish, light a taper, remove the thumb, and *at once* bring the taper to the mouth of the tube, *keeping the tube mouth downwards*; the gas takes fire: push the lighted taper into the tube; the flame of the taper goes out. Arrange another tube full of acidulated water over the platinum foil which is giving off the gas you have examined, and meanwhile remove the other tube (about

half full of gas) as already directed, turn it mouth upwards (keeping it closed by the thumb), light a splint of wood, allow it to burn for a little and then gently blow out the flame so that the wood continues to glow but not to burn with a flame, remove the thumb and

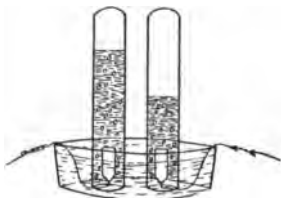


Fig. 9.

place the glowing end of the wood in the gas in the tube; the glowing splint of wood bursts into flame, but the gas in the tube does not take fire. When the third tube in which gas has been collecting is full of gas, close its mouth with the thumb, lift it out of the water, turn it mouth upwards, remove the thumb, and after ten or fifteen seconds bring a lighted taper to the mouth of the tube; nothing happens, the gas has gone; therefore this gas is considerably lighter than air. (You have already found that this gas puts out a burning taper, but itself takes fire.)

This experiment suggests that by the passage of an electric current through a mixture of dilute oil of vitriol and water, the water is separated into, and is, therefore, probably composed of, two colourless gases, one of which is very light, takes fire when a burning taper is brought near it, but extinguishes the taper when it is immersed in the gas,

while the other gas does not itself take fire, but causes a glowing chip of wood to burn brightly. The results of the experiment suggest, but do not prove, this conclusion: the gases obtained by passing the electric current through the acidulated water may have come from the materials other than water used in the experiment—namely, oil of vitriol, glass, and platinum—or they may have come from the air. To prove conclusively that the gases came, directly or

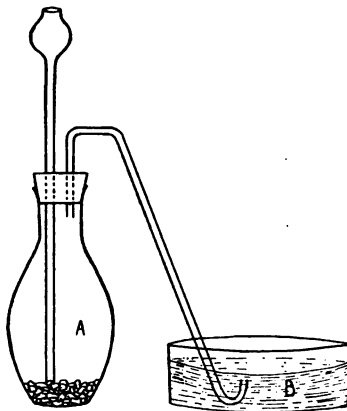


Fig. 10.

indirectly, from the water, it would suffice to prove that they did not come from any other of the possible sources; it would be extremely difficult to prove this negative statement conclusively. There is, however, another way whereby the suggestion stated above might be proved to be correct or incorrect: the quantity of each gas obtained by passing the electric current through a determinate quantity of water mixed with a determinate quantity of oil of vitriol might be found by careful experiment; if the sum of these

quantities of the two gases was exactly equal to the quantity of water which had disappeared in the process, and if the quantity of oil of vitriol remained unchanged, we should be justified in concluding that the water had been resolved or separated, directly or indirectly, into the two gases, and that therefore these gases were the components of water. This conclusion would be rendered quite certain did we succeed in causing determinate quantities of the two gases to unite, or combine, or become closely interwoven, so that water was obtained, and did we find that the quantity of water thus produced was equal to the sum of the quantities of the two gases by the union of which the water had been formed. Both these processes have been accomplished; the results leave no doubt that water is composed of the two gases which are formed when an electric current is passed through water acidulated by oil of vitriol.

But water appears when a candle is burnt in the air; hence the candle contains water, or it contains one or both of the components of water. Let us examine this matter more fully.

To make the inflammable gas already got from acidulated water.

Experiment 12.—The inflammable gas which was obtained by passing an electric current through acidulated water can be produced more easily by pouring oil of vitriol diluted with water on to zinc clippings. Arrange an apparatus as shown in Fig. 10; the bottle A is fitted with a good cork carrying a funnel-tube and an exit tube which passes under the water in a trough, B. Pour some oil of vitriol into about twenty times its volume of water while the water is kept constantly shaken, and allow this mixture to become cold; place some zinc clippings, or some granulated

zinc, in the bottle A; fill a couple of bottles with water, and invert them in the trough B. Now pour the diluted (cold) oil of vitriol, a little at a time, down the funnel-tube into the bottle; gas comes off and bubbles up through the water in B; after a minute or so, collect a test-tubeful of this gas, cover the mouth of the tube with the thumb, get a lighted taper ready, remove the thumb, and without reversing the tube, *at once* bring the lighted taper to the mouth of the tube; if the gas burns quietly the air is all out of the apparatus, if the gas takes fire with a slight explosion allow the evolution of gas to proceed for a minute or two more, and then collect another tubeful and test it as before. When the air is *quite* driven out of the apparatus fill the two bottles with the gas, and set the apparatus aside. Examine the gas in the bottles as already directed in the examination of the inflammable gas obtained by passing an electric current through acidulated water.

So far as these tests go, the gas now obtained by the action of diluted oil of vitriol on zinc is the same as the inflammable gas obtained by the electrolysis of acidulated water:—that the gases are identical has been proved by a complete examination of their properties. This inflammable gas is called *hydrogen*.

Let us find out what is produced when hydrogen is burnt.

To burn dry hydrogen and prove that water is formed.

Experiment 13.—Modify the apparatus for producing hydrogen from zinc and diluted oil of vitriol as shown in Fig. 11. The cylinder B contains *calcium chloride*, a substance that absorbs water very greedily; the exit tube from B is drawn out to a rather fine opening, *b*, Fig. 11. * Pour such a quantity of

* In place of such a cylinder as is figured in the text, two U shaped tubes may be used. A little cotton-wool should be placed on the surface of the calcium chloride in each U tube, or in the cylinder, and if a cylinder is used, the space beneath the calcium chloride should be *loosely* packed with cotton wool (*see a* in Fig. 11).

diluted oil of vitriol into the bottle A that gas is evolved moderately but not very rapidly; after a few minutes invert a dry

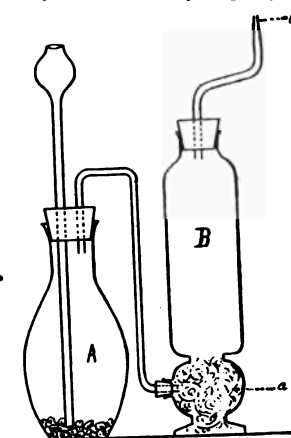


Fig. II.

test tube over the opening *b*; gradually draw this tube upwards, and the moment the mouth of it is drawn above the opening *b*, bring the tube, mouth downwards, to a flame; if the gas burns quite quietly, bring a light to the opening *b*; if however the gas in the small tube takes fire with a slight explosion it is unsafe to light the gas issuing at *b*. *On no account must the gas be ignited at *b* until a test, conducted as described, has proved that all the air has been swept out of the apparatus by the current of gas generated in A.* Allow the hydrogen to burn under a tube

attached to a U tube immersed in cold water, as described in experiment 3 (see Fig. 2, p. 5). Convince yourself that the liquid which you find in the U tube is water by determining its boiling point.

As the hydrogen formed in **A** passed through a considerable quantity of a material (calcium chloride) which very eagerly and rapidly absorbs moisture, the gas could not have contained moisture when it issued at *b*; hence it is clear that water is produced when dry hydrogen is burnt in air. Now we have found already that a candle contains hydrogen, or it contains this gas and also the other (non-inflammable) gas which is produced in the electrolysis of acidulated water, or it contains water. It must be remembered that the sum of the weights of water and carbonic acid gas which are formed when a candle is burnt in air is greater than the weight of candle burnt (see p. 9), also that a

burning candle absorbs a portion, or a constituent, of the air in which it burns (*see* p. 14), and that water is formed during the burning in air of dry hydrogen:—these facts taken together, and considered along with the result arrived at a moment ago, that hydrogen, or the non-inflammable gas obtained from water, or water, is a constituent of candle-stuff, make it probable, although they do not prove, that hydrogen is one of the components of a candle, and that the water which appears when a candle burns is formed by the burning of this component of the candle.

But, it is asked, may not air contain one of the gases, or both the gases, which are produced when an electric current is passed through acidulated water, and may not the water that appears during the burning of a candle be derived solely from the air wherein the candle burns?

In the next chapter it will be shown that air contains the same non-inflammable gas as is formed during the electrolysis of acidulated water, and also the same gas which remains when phosphorus, or a candle, has burnt in air (*see* p. 14), but that the inflammable gas (hydrogen) obtained by electrolysing acidulated water is not a constituent of air; meanwhile we shall base the next step in the inquiry on the assumption that this statement concerning the composition of air is correct. The non-inflammable gas which is obtained by the electrolysis of acidulated water is called *oxygen*. When hydrogen is burnt in air water is obtained; air does not contain hydrogen, but it does contain oxygen; water is composed of these two gases, hydrogen and oxygen, and these two gases only; hence, when hydrogen is burnt in air, this gas in some way unites so intimately with the oxygen in the air that the properties of both gases are merged, or disappear, in the properties of the water formed

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by the union of these gases. Candle-stuff is composed of carbon and some other substance or substances; one of these components of candle-stuff is either hydrogen, oxygen, or water itself; probably it is hydrogen; when a candle burns in air, water is obtained: hence, if we assume what has been shown to be very probable, that the candle contains hydrogen, we have a simple explanation of the source of the water which appears when the candle burns; on this assumption the water is produced by the intimate union of the hydrogen of the candle with the oxygen of the surrounding air. This conclusion is rendered more probable, in other words, the assumption on which it is based is strengthened, when the fact is recalled that a burning candle goes out when the surrounding air is removed (*see* p. 11); the air is needed in order that the candle may continue to burn, that is, in order that the production of water may be maintained; hence, probably the candle does not contain water, but only a constituent of water, and the other constituent of water is supplied by the air. The conclusion now arrived at concerning the source of the water which appears when a candle burns in air is in keeping with the fact that the sum of the weights of the carbonic acid gas and water produced when a candle burns exceeds the weight of candle burnt: this fact forces us to conclude that something is added to, or united with, the candle-stuff during the burning (*see* p. 10); now, if we suppose that a candle contains water which separates from it during the burning of the candle, as water exudes from a wet sponge when the sponge is squeezed, we must put down the whole increase in weight which accompanies the process of burning as due to the combination of something outside the candle with that

component of the candle which is not water, that is, with the carbon of the candle.

It remains then, at this stage, to inquire—What happens when carbon is burnt in air? Charcoal is approximately pure carbon; that something is formed when charcoal is burnt is evident to everyone who has used a charcoal fire. If one is in a room warmed by a charcoal

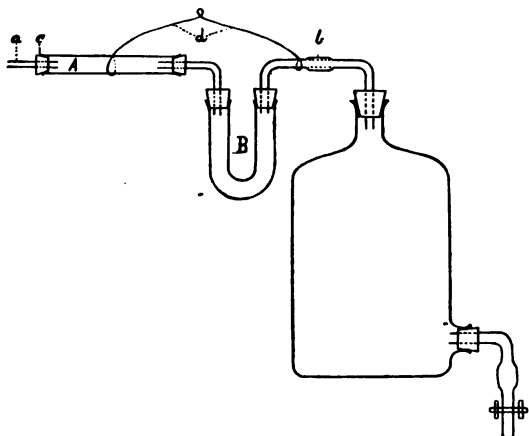


Fig. 12.

fire, one soon feels heavy, and listless, and headachy, unless the fire is burnt in an extremely good draught to carry off the products of combustion.

To show that carbonic acid gas is probably formed when charcoal is burned in air.

Experiment 14.—Twist one end of a piece of wire round a thin splinter of charcoal, and push the other end of the wire through a piece of cardboard sufficiently large to cover the mouth of a fair sized wide-mouthed glass jar or bottle; let the wire be about half as long as the height of the jar; set fire to the char-

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coal, bring it into the jar, and allow it to burn there as long as it will ; then pour some clear lime-water into the jar and shake it about ; the lime-water becomes turbid. .

This experiment suggests that carbonic acid gas is produced when charcoal is burnt in air. A thorough examination of the properties of the gas produced by burning charcoal in air makes it certain that this substance is carbonic acid gas. Carbonic acid gas is absorbed by caustic soda (*see* p. 9). Let us arrange an apparatus in which charcoal may be burnt and the carbonic acid gas retained.

To prove that the gas formed by burning charcoal in air weighs more than the unburnt charcoal.

Experiment 15.—The arrangement is shown in Fig. 12. The piece of rather wide glass tube A is fitted at one end with a cork which carries a short tube *a*, open at both ends, and at the other end with a good cork which carries a tube connecting A with a U-shaped tube, B. B contains pieces of stick caustic soda *slightly* moistened with water ; the exit tube from B is connected by a small piece of caoutchouc tube, *b*, with a large jar of water, as shown in the figure ; as the water runs out of this jar, air is sucked through A and B. Disconnect the caoutchouc tube at *b*, and attach A and B to one end of the beam of a balance by the wire *d* ; place three or four small thin splinters of charcoal on the pan of the balance, and counterpoise the whole by putting pieces of metal and small shot on the other pan. Now attach the caoutchouc tube at *b*, open the stop-cock of the large jar so that the water flows out, loosen the cork *c* of the tube A, take the pieces of charcoal in a pair of tongs, ignite the charcoal, drop it into A, and *at once* place the cork *c* firmly in the wide tube A ; heat the tube A by a Bunsen-lamp, and regulate the flow of water from the jar so that the current of air is kept at such a rate as insures the slow burning of the charcoal. When the charcoal is burnt, detach the caoutchouc tube at *b*, *allow the tube A to cool*, and set the

balance swinging; you see that the apparatus now weighs more than it did before the charcoal was burnt.

Hence the carbonic acid gas which is produced by burning charcoal in air is formed by uniting the air, or a portion of the air, with the charcoal. To make this conclusion certain, it would be necessary to prove that the weight of the material of the vessels in which the experiment just described was performed underwent no change during the process.

It does not seem probable that the whole increase of weight which accompanies the burning of a candle is due to the combination of the carbon of the candle with something in the air wherein the candle burns.

We have now brought together a mass of evidence which points very distinctly to the conclusions that candle-stuff is composed of two things at least, carbon and hydrogen; that when candle-stuff is burnt in air the carbon of the candle unites with, or becomes closely interwoven with, the oxygen which is present in the air, thus producing carbonic acid gas; and that, during the burning of the candle, the hydrogen, which is one of the components of the candle, enters into intimate union with the oxygen contained in the air, and thus produces water.

When we have learnt more of the compositions of water and carbonic acid gas, we shall be able to devise an experiment by which the tentative conclusions now arrived at may be firmly established (Chapter ii. pp. 42-44). Suffice it to say here that it is not possible to find out exactly what changes occur during the burning of a candle without determining accurately the weight of candle burnt, the weight of each substance produced, and the *quantitative*

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composition of each substance produced ; the final experiments must be quantitative ; we must account for everything that has taken any part in the process of change when that process is completed.

We have now arrived at a fairly definite conception of some of the changes that take place when a candle burns ; but as yet we are only on the threshold of the subject.

We have proceeded by comparing one occurrence with another, by acting on the clues suggested by some event in order to find out more about that event, and more about events like it ; we have made guesses or hypotheses, and have tried to draw conclusions therefrom so exact that they might be subjected to the test of experiment ; the results of one experiment have suggested other experiments ; the more we proceeded the more necessary have we found it to be to weigh and measure the materials concerned in the changes we have been trying to understand. We have found that the substances which are obtained by burning a candle under ordinary conditions are not directly recognisable by the senses ; we have learnt that definite substances may exist which we neither see, nor taste, nor smell, nor hear, nor are able to touch. We have found that the products of the combustion of candle-stuff are very different from the substances which by their union form these products. There could hardly be three things less alike in their prominent properties than water, carbonic acid gas, and a candle.

CHAPTER II.

COMPOSITIONS OF SUBSTANCES CONCERNED IN THE BURNING OF A CANDLE.

IN Experiment 8 (p. 12) a piece of phosphorus was burnt in an enclosed portion of air; some part of the air was absorbed by the burning phosphorus; a burning taper was extinguished by the air which remained when the phosphorus had ceased to burn; further, the residual air did not give any turbidity with lime-water, therefore it was not carbonic acid gas.

To prove that phosphorus burning in air withdraws about one-fifth of the volume of the air wherein it burns.

Experiment 16.—From one end of a glass cylinder or piece of tubing about 14 inches (35 centim.) long and 3 inches ($7\frac{1}{2}$ centim.) wide, measure off about 2 inches (5 centim.), and divide the space from this point to about $\frac{1}{2}$ inch ($1\frac{1}{4}$ centim.) from the other end into five equal parts, marking each division by a piece of paper gummed on the outside of the cylinder. Into a flat dish, about 9 inches ($22\frac{1}{2}$ centim.) diameter, and not less than 6 inches deep, pour water till its depth is the same as the length from the mouth of the cylinder to the point whereat the division into fifths begins (in this case about 2 inches). Close the upper end of the cylinder by a good cork projecting about $\frac{1}{2}$ -inch inside the cylinder (*i.e.*, to the point whereat the division into fifths ceases); let the cork carry a *short* piece of glass tubing with a greased stopcock on it, or let the upper end of the short tube be covered with a little bit

of caoutchouc tubing with a good pinch-cock on it as close to the glass tube as possible (Fig. 13). Cut a piece of phosphorus about ten times as large as a pea, dry it rapidly by *slight* pressure between filter-paper, place it in a little crucible stuck in a cork, float the cork on the surface of the water in the dish, set fire to the phosphorus, quickly cover the phosphorus

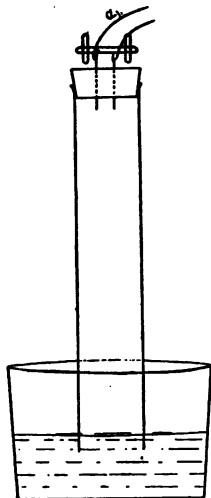


Fig. 13.

with the glass cylinder, the stopcock being open, and *at once* close the stopcock so that the air inside the vessel is securely cut off from the outer air. As the phosphorus burns, you notice that the water rises inside the glass cylinder; from time to time pour a little water into the flat dish; when the phosphorus has stopped burning, and the cylinder has become cold, pour water into the flat dish until the levels of the water outside and inside the cylinder are the same. You notice that the air remaining in the cylinder now occupies about four-fifths of the space occupied by the air before the combustion; in other words, about one-fifth of the whole volume of air has been absorbed by the burning phosphorus.

When phosphorus burns in air, then, it removes about one-fifth of the bulk of air in which it burns.

To prove that iron filings rusting in moist air withdraw about one-fifth of the volume of the air.

Experiment 17.—Clean out the cylinder and glass dish used in the last experiment. Put about the same quantity of water as before into the dish. Place about 6 oz. of fine iron filings or borings in a little muslin bag. Moisten the filings *thoroughly*, and suspend the bag over, and not very far from, the water in

the dish ; * cover this arrangement with the glass cylinder, close the stopcock, and set the apparatus aside. The water *slowly* rises in the cylinder ; when the rise stops (which will be after about twenty-four hours) pour water into the dish until the levels outside and inside the cylinder are the same. You find that the air now remaining occupies about four-fifths of the original volume. Attach a glass tube to the tube with the stopcock passing through the cork in the cylinder (a, Fig. 13), keeping the stopcock closed, let the lower end of this tube be turned slightly upwards, and let it dip under water in a trough. Remove the whole apparatus, and sink the glass dish and the lower end of the cylinder a little way beneath the water in a deep trough. Remove the glass dish, depress the cylinder in the trough, and collect two small bottlefuls of the air that is thus driven out of the cylinder (refer to experiment 8, p. 14). Examine this air or gas ; it extinguishes a lighted taper, it does not produce any turbidity in lime-water, and it is about as heavy, bulk for bulk, as common air (*see* p. 14). Examine the iron filings in the muslin bag ; you find that the iron is rusted on the surface.

The great similarity between the results of this experiment and those of experiments 8 and 16 makes it very probable that the processes which occur when phosphorus is burnt in air, and iron rusts in wet air, are much alike ; both probably consist in the withdrawal from the air of a portion or constituent thereof, and the leaving behind of another constituent which is not able to support the burning of a taper.

Air then seems to be composed of at least two different gaseous substances ; one which is removed when phosphorus burns or iron rusts in air, and another which remains when the burning or rusting is completed ; and

* This is easily done by making a little wire stand with three legs, resting this on the bottom of the flat dish inside the cylinder, and suspending the bag from the top of this stand.

the gas which is removed during burning or rusting seems to compose about one-fifth of the bulk of the air.

Certain common metals, such as lead and tin, undergo a kind of slow burning without flame when they are heated in air. Let us examine this a little.

To prove that the substance obtained by strongly heating zinc, tin, or lead in air weighs more than the unburnt zinc, tin, or lead.

Experiment 18.—Place a little granulated zinc, about $\frac{1}{2}$ ounce (10 grams), in a thin crucible, and about the same quantity of tin-leaf in another crucible; in each crucible place a little piece of glass rod, and counterpoise both crucibles separately with the glass rods in them, on a moderately fine balance; place the crucibles on triangles and heat them, at first gently, then strongly, by Bunsen lamps. Continue to heat, stirring frequently by means of the pieces of glass rod, until most of the zinc has been changed to a yellowish powder, and most of the tin to a white powder; allow to cool, and counterpoise again. You find that the powders produced by heating zinc and tin in air weigh more than the metals did. Hence something has been added on to, or combined with, the zinc and the tin. Repeat this experiment with lead in thin pieces; the result is similar to that obtained with zinc and tin.

This experiment suggests that the process which takes place when zinc, lead, and tin are heated in air until they are changed into powdery substances unlike the original metals, *may* consist in the combination with these metals of that constituent part of the air which is absorbed by phosphorus when it burns, and by iron when it rusts in air. If the product of burning lead in air is formed by the union of the lead with a constituent of the air, it might be possible to obtain this constituent of air again from the burnt lead. Now *red lead* is formed by burning lead in a

stream of air. Let us see what can be done with red lead.

To obtain from red lead a gas wherein burning bodies burn very brilliantly and rapidly.

Experiment 19.—Place about $\frac{1}{2}$ ounce (10 grams) red lead, which has been dried by heating over a low flame, in a dry tube of hard glass about 4 to 5 ins. (10 to 12 $\frac{1}{2}$ centims.) long, and about $\frac{1}{2}$ in. (1 $\frac{1}{4}$ centims.) diameter; close the tube by a good cork, carrying a glass tube bent as shown in Fig. 14, and

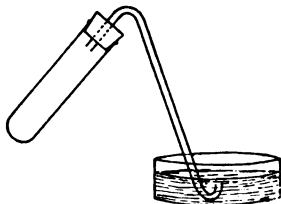


Fig. 14.

arranged so that any gas coming off by this tube can be collected in the usual way over water. Fill two small bottles with water, and invert them in the trough. Now heat the glass tube, at first slightly, and then little by little increasing the temperature, beginning to heat from the upper surface of

the red lead and passing the flame slowly downwards. When the red lead is very hot gas begins to bubble up through the water in the trough; allow this gas to escape for a few seconds, and then fill the two bottles with it. When the bottles are full, remove the end of the delivery-tube out of the water before you take away the flame from under the tube containing the red lead; otherwise, as this tube cools, water will rush back and break the tube. Have ready a taper, a little bit of phosphorus, and a piece of wire bearing a little cup on its lower end and passing through a metal plate large enough to cover the mouth of either of the bottles you have filled with gas. Light the taper, reverse one of the bottles, and dip the lighted taper into it; the taper burns rapidly and brilliantly. Place the piece of phosphorus in the little cup, ignite the phosphorus by heating the cup for a moment in a lamp-flame, and plunge the lighted phosphorus into the second bottle of the gas; the phosphorus burns very brightly, giving off a thick white smoke

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and emitting much light. Examine the solid that is left in the tube; you will notice specks of lead disseminated through the red powder.

If you consider that phosphorus burns fairly brightly in air, that as it burns it absorbs a constituent portion of the air, and that the air which remains is incapable of supporting combustion, you will be prepared to admit that if the constituent of the air which is seized on by the burning phosphorus could be obtained apart from the other component of the air which puts out a burning body, the flame-supporting constituent might be expected to cause a burning body to burn very rapidly and brilliantly; that is to say, the flame-supporting constituent of air might be expected to behave as the gas you have just obtained by heating red lead does behave towards burning phosphorus or a burning taper. Moreover, if red lead is formed by combining lead with a constituent of air, you ought to get the lead back again when you remove this constituent from the red lead.

When mercury is heated to about its boiling point in air, a red powder is very slowly formed on the surface of the mercury; this process is similar to that which was carried out with lead, zinc, and tin in experiment 18, only it takes place much more slowly. Let us examine this red powder, or burnt mercury.

To obtain from burnt mercury a gas wherein burning bodies burn very brilliantly and rapidly.

Experiment 20.—Conduct an experiment similar to No. 19, but in place of red lead use burnt mercury or *red precipitate*. Gas comes off, and this gas is found to cause a burning taper, and burning phosphorus, to burn very brilliantly. An inspec-

tion of the tube after heating shows the presence of many small globules of mercury.

To complete the proof of the assertion that when lead or mercury is burnt in air the metal combines with a constituent of the air, and that this constituent is obtained by strongly heating the burnt lead or burnt mercury, it would be necessary to burn a determinate weight of one of these metals in a measured volume of air, to measure the diminution in the volume of the air which takes place when all the metal is burnt, to weigh the burnt lead or burnt mercury which is obtained, to heat this weighed quantity strongly until gas comes off, to measure the gas, and to weigh the lead, or mercury, which remains. Such a series of quantitative experiments was carried out by Lavoisier in the seventies of last century.

Lavoisier placed mercury in a glass balloon, the neck of which was drawn out and bent round so as to pass under mercury in a glass dish, and to project above the surface of the mercury into a graduated jar; the air in the balloon was thus in communication with the air in the graduated jar, but the mercury in the glass dish served as a trap to cut off communication with the outer air. The mercury was heated nearly to its boiling point for 12 days, after which time no further diminution occurred in the volume of air inside the apparatus; the diminution was measured by noting the rise of the mercury in the graduated jar. As the heating proceeded red specks appeared on the surface of the mercury; these were collected, weighed, and placed in a little bulb, with a long neck which was bent so as to pass under mercury, contained in a small trough, into the mouth of an inverted graduated jar filled with mercury and secured with its mouth under the mercury in the trough.

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The red powder was heated ; the gas which came off was collected in the graduated jar, and was measured.

Lavoisier's results, when translated into English weights and measures, were as follows :—

Four ounces of mercury were placed in the balloon.

Volume of air in graduated jar before

burning the mercury . . . = 50 cub. inches.

Volume of air in graduated jar after

burning the mercury . . . = $42\frac{1}{2}$ „

Volume of air which had disappeared

during the process . . . $7\frac{1}{2}$ „

Weight of burnt mercury obtained . . . = 45 grains.

Volume of gas obtained by heating this 45

grains of burnt mercury = $7\frac{1}{2}$ cub. inches,

weighing . . . $3\frac{1}{2}$ „

Weight of mercury obtained by heating this

45 grains of burnt mercury . . . = $41\frac{1}{2}$ „

Sum of weights of gas and mercury obtained

by heating 45 grains burnt mercury . 45 „

Everything which had taken part in the process was accounted for: the whole of that constituent of the air which had disappeared during the burning of the mercury was obtained again; the whole of the mercury which had been burnt into the red specks was obtained again; and the weight of the mercury which was burnt, added to the weight of the air-constituent which was absorbed by the mercury in the process of burning, was exactly equal to the weight of the burnt mercury which was formed.

These experiments, made by the great founder of the

science of Chemistry, elucidated fully and completely the change of composition which occurs when mercury is burnt in air.

We will now examine a little more fully the properties of the flame-supporting constituent of air. This gas is most easily prepared by heating an intimate mixture of finely powdered dry *chlorate of potassium* with about one-fourth of its weight of dry powdered *manganese dioxide*.*

To make and examine the gas already got from red lead and burnt mercury.

Experiment 21.—Arrange an apparatus like that used in experiment 19; put sufficient of the dry mixture of potassium chlorate and manganese dioxide into the tube to make it about half full; fill four bottles with water, and invert them in the water-trough. Heat the mixture in the tube from the top downwards, gradually raising the temperature; allow the first portions of the gas that come off to escape, and then fill the four bottles with the gas. Burn a piece of candle, attached to a wire, in the first bottle, a thin slip of charcoal in the second, a little bit of phosphorus in the third, and a small quantity of zinc-dust in the fourth; in each case start the burning before the substance is plunged into the bottle, and when the burning is over cover the bottle with a plate of glass or a piece of cardboard. Now pour a little clear lime-water into the bottles wherein the candle and the charcoal were burnt; the turbidity that is produced in the lime-water shows that carbonic acid gas is present in each bottle. Hence the gas formed by burning candle or charcoal in this flame-supporting constituent of air is the same as the gas which is formed when these substances are burnt in ordinary air. Examine the substance formed by burning the zinc-dust; it is a yellowish powder resembling that

* The student need not trouble at present to know more of the properties of these bodies. He must regard the directions now given as purely an empirical recipe for making the gas he is to examine.

produced by burning zinc in air (*compare* experiment 18). During the burning of the phosphorus a thick white smoke was formed, but this has now disappeared ; pour a little water into this bottle, shake it up and add a few drops of blue *litmus-solution* ; the blue colour changes to red ; pour a little of the same blue litmus-solution into a clean bottle, add some water and shake ; no visible change takes place. Therefore something is formed when phosphorus is burnt in the flame-supporting constituent of air which is not present in the air, and when this something is dissolved in water the solution turns blue litmus red.

We have already found that two gases are obtained by passing an electric current through acidulated water.

To get from acidulated water a gas which is probably the same as the gas made in Experiment 21.

Experiment 22.—Experiment 11 should now be repeated, the passage of the current being continued until a tubeful of the gas which is produced the more slowly of the two has been obtained ; a piece of charcoal should be burnt in this gas, and the presence of carbonic acid gas should be proved after the burning is finished.

As far as these experiments go, it appears that the flame-supporting gas which is one of the constituents of water is the same as the flame-supporting constituent of common air. This conclusion, which has already been assumed to be true (p. 24), has been verified by quantitatively comparing* the properties of the gases obtained from water and air respectively.

This gas which is present in both water and air, and

* The meaning of the phrase *quantitatively comparing*, will be apparent by considering experiments 16 and 17, made with phosphorus and iron.

which is characterised by the property of supporting combustion, we already know by the name of *oxygen*. Oxygen enters into the composition both of water and air.

We have already obtained oxygen from red lead (*Experiment 19*); we have also learned (*see pp. 20, 21*) that water is formed by the union of oxygen with hydrogen. Hence, if hydrogen is passed over heated red lead we may fairly expect to get water formed. Let us try.

To pass dry hydrogen over red lead and obtain water and lead.

Experiment 23.—Set up an apparatus to prepare dry hydrogen, as described in experiment 13 (p. 22), but let the exit tube pass through a cork which is fitted into a piece of *hard* glass tubing about 4 inches (10 centim.) long (*a*, Fig. 15); fix a good cork in the other end of this piece of tubing, and let this cork carry a tube bent at right angles, and dipping into a small *dry* flask, arranged so that it may be surrounded by cold water (*b*, Fig. 15). Place about $\frac{1}{2}$ oz. (10 grams) *dry* red lead in the hard glass tube *a*, spreading it out so as to extend along the greater part of the tube. Pour the acid on to the zinc in the bottle, turn the tube *b* with its open end upwards, and after a few minutes collect a small tubeful of the gas, and test whether it is free from air (*see* directions in experiment 13, p. 23). As soon as the air is quite driven out of the apparatus, *but not until you are certain that this is the case*, turn the exit tube down so that it dips into the small flask, and begin to heat the tube containing the red lead; heat at first gently, and then more strongly, until the tube is red hot, taking care to keep a brisk stream of hydrogen passing through the tube. After a little you see drops of a colourless liquid forming in the exit tube, and collecting in the flask. Keep the process going until you have collected enough liquid to determine its boiling point (*see* experiment 3, p. 6). The liquid is water. Notice that a considerable amount of metallic lead has made its appearance in the tube where the red lead was heated. Maintain the stream

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of hydrogen while the tube cools, and do not take the apparatus to pieces until the parts are nearly cold.

There can be no doubt now about the composition of water. Water is composed of oxygen and hydrogen. Red lead is composed of lead and oxygen; when this substance is heated in a stream of hydrogen, water is produced by the union of the hydrogen and oxygen, and the removal of the oxygen from the red lead leaves the metal lead behind.

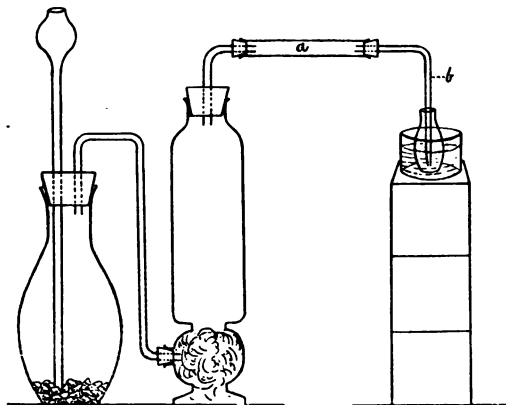


Fig. 15.

The experiment just made, of obtaining water by passing hydrogen over heated red lead, suggests a method for determining the quantities of hydrogen and oxygen which go to make up a determinate quantity of water—that is, for determining the quantitative composition of water. If the red lead had been weighed before and after the experiment, the loss of weight undergone by the red lead would have represented the oxygen which had combined with hydrogen ;

and if the water formed had been weighed, the difference between this weight and the weight of oxygen (found as just described) would have given the weight of hydrogen which had combined with the determined weight of oxygen to form the determined weight of water. Many experiments have been conducted on the lines indicated, the substance formed by the union of copper with oxygen being employed in preference to red lead. The result of these experiments is that, in round numbers, nine parts by weight of water are composed of one part by weight of hydrogen, united with eight parts by weight of oxygen.

We are not yet quite prepared to devise an experiment by which to prove the tentative conclusion arrived at in Chapter I., that candle-stuff is composed of carbon and hydrogen, and that when a candle is burnt the carbon combines with oxygen in the air to form carbonic acid gas, and the hydrogen of the candle also combines with oxygen in the air to form water (*compare* p. 28 where this statement is deduced as a probable conclusion from the facts then learned). Before this experiment can be devised, we must learn how to make a quantitative determination of the composition of carbonic acid gas, and we must make ourselves acquainted with the results of this determination.

The facts now known to us that carbonic acid gas is produced when charcoal is burnt in oxygen, and that carbonic acid is easily absorbed by caustic soda, suggest a method whereby the quantitative composition of this gas may be determined. It would only be necessary to burn a definite and determined weight of pure carbon—charcoal is carbon with small quantities of various impurities—in a stream of pure oxygen, to absorb the whole of the carbonic acid gas thus formed in a suitable apparatus containing

caustic soda, and to determine the weight of this apparatus before and after the experiment : the gain in weight of the apparatus would give the weight of carbonic acid formed ; the weight of carbon which has produced this weight of carbonic acid is known ; and as carbonic acid is composed of carbon and oxygen, the difference between the weight of carbon burnt and carbonic acid produced therefrom, would give the weight of oxygen which had united with the determined weight of carbon to produce the determined weight of carbonic acid. Experiments of this kind have been conducted with great care ; diamond being employed as the purest form of carbon. The results are, in round numbers, that eleven parts by weight of carbonic acid gas are composed of three parts by weight of carbon, united with eight parts by weight of oxygen. If candle-stuff is composed of carbon and hydrogen, and of these bodies only, then the composition of candle-stuff might be determined by burning a definite quantity of candle, the weight of which had been determined, in a stream of oxygen, and finding the weights of water and carbonic acid produced, by absorbing the former in a weighed U-tube containing calcium chloride (*compare* experiment 13, p. 22), and absorbing the latter in a weighed apparatus containing caustic soda ; the increase in the weight of the tube containing calcium chloride would represent the weight of water formed from the determined weight of candle, and the increase in the weight of the caustic soda apparatus would represent the weight of carbonic acid formed from the same weight of candle. Then, knowing that $\frac{1}{8}$ of any determinate weight of water is hydrogen, and $\frac{3}{11}$ of any determinate weight of carbonic acid is carbon, it would be easy to calculate, from the experimentally determined results, the weights of

carbon and hydrogen in the weight of candle-stuff used in the experiment.

Paraffin candles are composed of carbon and hydrogen ; tallow and stearin candles and many other kinds of candles contain some oxygen also.

We have now arrived at some notion of the changes that occur in the compositions of the substances which take part in certain processes of burning or combustion. As phosphorus burns in air, a certain definite kind of matter that forms a part of the air, called oxygen, enters into intimate union with the phosphorus, and there is thus produced a white solid which dissolves in water to form a liquid that changes the colour of litmus-solution from blue to red ; the air which remains, which is ordinary air robbed of its oxygen, does not support the combustion of a burning body. As carbon burns in air, the oxygen of the air becomes so interwoven with the carbon that neither the carbon nor the oxygen can be recognised in the product of this interweaving—called carbonic acid—by any of the properties which characterise carbon and oxygen separately ; the air being deprived of its oxygen by this process, there remains a non-oxygenised air wherein a burning body is unable to continue burning. Similar processes occur when lead and mercury are heated in air ; the lead and the mercury combine so closely with the oxygen of the air that the products, which are composed of lead and oxygen, or of mercury and oxygen, as the case may be, have properties quite different from those of their components ; the air which remains in either case is incapable of supporting combustion, it is air from which the oxygen has been removed. The substance formed by the union of phosphorus with the oxygen of the air wherein

the phosphorus burns is easily removable from the residual air by shaking with water ; the substances formed by the union of lead and mercury with the oxygen of the air wherein these metals are burned, are solids, and are therefore separated by their own properties from the residual air ; but the substance formed by the union of carbon with the oxygen of the air wherein the carbon is burnt is a gas, and therefore when the burning is finished there remains a mixture of this gas—carbonic acid—with the residual, flame-extinguishing air ; therefore it is more difficult to unravel the process which takes place when carbon burns in air than it is to follow the changes that occur when lead or mercury is burnt in air. When we come to the burning of a candle we find that the occurrence is yet more complicated. The candle itself is not composed of one substance, or one kind of matter ; it is made up of two, and sometimes of three, distinct substances, carbon, hydrogen, and sometimes oxygen also. Two different substances are formed by the union of the components of the candle with the oxygen of the air,* namely, carbonic acid gas and water-gas, and both these products of combustion are gases under the conditions of the process ; hence when the burning is finished we have the gaseous products of combustion mixed with the flame-extinguishing constituent of air which remains when the burning candle has removed the oxygen from the air in which it has burnt.

The student will now see, I think, why it was necessary to turn his attention for a time to instances of burning which are less complex than that common case of

* If the candle itself contains oxygen, this oxygen is used in helping the oxygen of the air to burn the carbon and hydrogen of the candle.

combustion, the burning of a candle, which first claimed his consideration.

The air or gas which remains when ordinary air is deprived of its oxygen by a burning body is called *nitrogen* (*nitre-former*; it is a component of nitre or salt-petre). We have studied the properties of this body sufficiently for the present; it is about as heavy bulk for bulk as common air; it is colourless, tasteless, inodorous; it does not form any solid when shaken with lime water, and it does not support the combustion of bodies which are burning before they are brought into it. (*See experiments 8 and 17; pp. 14 and 32.*)

As about one-fifth of any determinate volume of air is composed of oxygen, a gas wherein burning bodies burn brilliantly and rapidly, and about four-fifths is composed of nitrogen, a gas wherein burning bodies cease to burn, and as the behaviour of air towards a burning taper is what we should expect the behaviour to be of a mixture of two gases one of which causes burning to proceed very rapidly while the other stops burning altogether, we might fairly expect to be able to re-form air by adding to the nitrogen which remains when phosphorus has been burnt in an enclosed quantity of common air, a volume of oxygen equal to one-fifth of the volume of the air which was present before the burning began.

To remove oxygen from air by burning phosphorus, and re-form air by adding oxygen to the gas which remains when the phosphorus has ceased to burn.

Experiment 24.—Arrange an apparatus similar to that described in experiment 16 (p. 30); do not trouble to divide the cylinder into five parts, but make a mark on the cylinder at

the level of the water in the dish before the burning begins. Start the burning of a fair sized piece of phosphorus (as directed on p. 31). While the phosphorus is burning, prepare a quantity of oxygen equal to about half the contents of the glass cylinder wherein the phosphorus is burning (*see* experiment 21, p. 38). When the combustion is over, and the apparatus is cold, equalise the levels of the water inside and outside

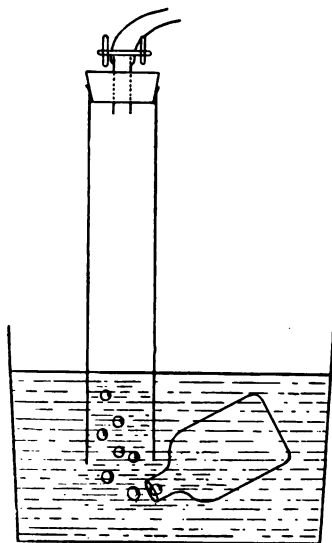


Fig. 16.

the cylinder, and mark the level of the water on the cylinder. Now remove the cylinder, standing in the dish, to a deep trough of water and clamp it there, mouth-downwards under the water; remove the dish; place the bottle of oxygen mouth-downwards in the trough, withdraw the stopper (or the plate which covers the mouth of the bottle), bring the bottle near the cylinder, so that when the bottle is tilted out of the vertical the oxygen in

the bottle will bubble up into the cylinder (*see* Fig. 16). Let the oxygen pass up into the cylinder until the level of the water in the cylinder is depressed to where it stood before the burning of the phosphorus began. You have now restored the oxygen which the burning phosphorus removed from the air. Cover the mouth of the cylinder with a glass plate, lift it out of the trough, shake it repeatedly so as to mix the gases in it; withdraw the plate and plunge a lighted taper into the cylinder; the taper burns as it does in air. Hence, so far as the result of this experiment goes, it seems that you have reproduced ordinary air.

It is then possible to take away oxygen from air by burning phosphorus in the air; and it appears to be possible to reproduce the original air by adding to the nitrogen, which remains when the phosphorus has ceased to burn, the same quantity of oxygen as has been removed by the phosphorus.

The properties of air, then, are not very different from the properties of its components, oxygen and nitrogen.* The oxygen is recognised in the air by the taper—the taper burns; the nitrogen is also recognised by the taper—the brilliant burning which would take place in pure oxygen is toned down by the flame-extinguishing nitrogen: the nitrogen tries to put the taper out, but it cannot wholly succeed; the oxygen tries to make the taper flare up and burn rapidly, but it is restrained by the quenching influence of the nitrogen.

The prominent properties of a candle, on the other hand, are very different from those of its components, hydrogen, carbon, and perhaps oxygen. We cannot see the particles of black solid carbon, nor the particles of

* There are small quantities of other things present in air, but we need not mind about these at present (*compare* p. 57).

colourless gaseous hydrogen or oxygen, in the particles of candle-stuff, however finely we may grind, or rasp, or powder the candle; nor can we produce a candle by mixing its components together. Yet the carbon and the hydrogen are there, and they are proved to be there by the facts, that when a candle is burnt in air the same substances are produced—carbonic acid and water—as are formed when carbon and hydrogen are burnt separately in air; and that the weights of carbonic acid and water formed by burning a determinate weight of candle are the same as the weights of those substances obtained by burning separately the weight of carbon, and the weight of hydrogen, which are calculated to be present in the weight of candle burnt by reasoning from the known and fixed compositions of carbonic acid and water.*

The changes which occur when a candle burns are representative *chemical* changes. The substances that are formed when a chemical change takes place are unlike those by the interaction of which they have been formed; the substances formed differ from the original substances both in composition and properties. Another representative chemical change which has been glanced at is that which occurs when chalk is heated. The result of experiment 9, p. 16, proved that a gas is given off when finely divided chalk (whitening) is strongly heated, and that a white solid is produced by passing this gas into clear lime-water.

* This statement should be compared with the facts and arguments on pp. 24, 25. The reasoning here adopted assumes that the compositions of carbonic acid and water are always the same; this matter will be gone into in the next chapter.

To decompose whitening by heat and examine the difference between the substances so formed and the original whitening.

Experiment 25.—In a thin porcelain crucible place about 30 grains (2 grams) whitening, cover the crucible with its lid, and counterpoise the whole on a fairly delicate balance. Now heat the crucible to bright redness for fully an hour by means of a large and powerful Bunsen lamp; allow to cool, and counterpoise again. The crucible and its contents weigh distinctly less than before heating; therefore something has been removed from the whitening by the process of heating. Shake out the residue into a beaker, and moisten it with water; after a little add some more water, notice if any visible change occurs, and then pour a little muriatic acid into the beaker; the white solid slowly dissolves *without any effervescence*. Place a little whitening in another beaker, moisten it with water, after a little add more water, and then some muriatic acid; the solid dissolves and the act of solution is accompanied by *the evolution of gas*.

Now place a little whitening in a small flask with a cork carrying a funnel-tube, and an exit-tube bent twice so as to pass down into a beaker. Pour a little muriatic acid on to the whitening, and a little clear lime-water into the beaker. The gas which comes off bubbles through the lime-water and produces a white solid therein.

Therefore the substance which is obtained by strongly heating whitening is different from whitening, and the difference seems to consist in the presence or absence of a gas.

Now we have already found that the gas which is given off when whitening or chalk is strongly heated causes clear lime-water to become turbid, therefore it is very probable that the gas produced by acting on whitening with muriatic acid is the same as that produced by strongly heating whitening; and it is pretty clear from the evidence of

other experiments already made that this gas is carbonic acid.

If the gas produced from whitening is carbonic acid, it would probably be possible to re-form whitening or chalk by adding carbonic acid gas to the substance which remains when whitening is strongly heated.

To decompose whitening by heat, and re-form whitening by adding carbonic acid to the substance which remains when the whitening is decomposed.

Experiment 26.—*Strongly heat* a little whitening, about 15 grains (1 gram), as directed in experiment 25, but without counterpoising the crucible and its contents, for an hour; allow to cool, add water, shake up, and add more water until the solid is all dissolved. Make carbonic acid, by acting on marble with muriatic acid, and lead it into this solution; collect the white solid that forms, wash it with water 3 or 4 times, and dry it over a *low* flame; place the dry solid in a flask, add muriatic acid, and let the gas which comes off pass into clear lime-water. The formation of a white solid in the lime-water makes it very probable that the solid you have obtained by passing carbonic acid gas into an aqueous solution of the residue left when whitening was strongly heated is itself whitening or chalk.

The substance produced by strongly heating chalk until gas ceases to be given off is lime. The change from lime to chalk, and that from chalk to lime, are representative chemical changes. The addition of carbonic acid gas to lime transforms it into chalk, and the removal of carbonic acid gas from chalk changes it into lime. The carbonic acid gas cannot be seen in the chalk, nor can it be detected therein by taking advantage of the properties which characterise the gas when it is separated from lime. The gas is so intimately united with the lime that the two

together form a distinct and definite kind of matter, which is different in its properties, as it is different in its composition, both from lime and carbonic acid gas.

We have now become acquainted with several distinct kinds of matter, each characterised by properties peculiar to itself; these kinds of matter are called oxygen, hydrogen, nitrogen, carbonic acid, chalk, lime, water, and carbon.

The method we used in examining the changes that occur when a candle burns began by making observations; the results of observation suggested questions, to which answers were found by making experiments; these answers generally contained in themselves fresh questions, which in their turn were subjected to the test of experiment; when a certain amount of connected facts had thus been gathered together, a guess was made, an hypothesis was started, to account for the facts; predictions were made from this hypothesis, and these predictions were examined by subjecting them to observation and experiment. For instance, the observation that a candle disappears as it burns suggested the question: Is the candle-stuff destroyed, or only changed into other forms of matter? To this question experiment gave the answer, which was itself also a question—there is a change in the form of the candle-stuff, and the new stuff produced weighs more than the candle weighed; find out why it weighs more. An hypothesis was then started—the products of burning weigh more than the candle, therefore, the burning candle probably seizes upon something outside itself, and as the candle burns in the air perhaps this something is in the air. This hypothesis suggested that if something is removed from the air by the burning candle, a decrease in

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the quantity of the air must take place as the candle burns; this suggestion was put to the test of experiment, and was found to be correct.

This is the scientific method, and the scientific method is only common sense made accurate.

CHAPTER III.

ELEMENTS AND COMPOUNDS.

WE have learnt that candle-stuff is composed of carbon and hydrogen, and sometimes also of oxygen ; that carbonic acid and water are produced when a candle is burnt in air, and that carbonic acid is composed of carbon and oxygen, and water is composed of hydrogen and oxygen. The argument which was used in the last chapter (*see* p. 49), to prove the presence of carbon and hydrogen in candle took for granted the fact that the compositions of carbonic acid and water are fixed and invariable.

A determinate weight of pure carbonic acid is always composed of carbon and oxygen, and of these substances only, and the weight of oxygen is always two and two-thirds times as great as the weight of carbon ; a determinate weight of pure water is always composed of hydrogen and oxygen, and of these substances only, and the weight of oxygen is always eight times as great as the weight of hydrogen. These conclusions have been arrived at by making very careful analyses and syntheses of many different specimens of carbonic acid and water. When pure carbon is burnt in plenty of oxygen, two and two-thirds grains of oxygen invariably combine with one grain of carbon to form $3\frac{2}{3}$ grains of carbonic acid, and the rest of the oxygen remains unaffected by the carbon. If 1 grain or 1 lb., or 1 ounce, or 1 gram of hydrogen is mixed with

8 grains, or 8 lbs., or 8 ounces, or 8 grams of oxygen, and an electric spark is passed through the mixture, the whole of the hydrogen and the whole of the oxygen disappear, and 9 grains, or 9 lbs., or 9 ounces, or 9 grams of water are formed ; if there are more than eight parts by weight of oxygen for each part by weight of hydrogen, the excess of oxygen—that is, whatever is present over and above the eight parts by weight—remains unchanged ; if more than one part by weight of hydrogen is present for eight parts of oxygen, the excess of hydrogen remains unchanged.

These two substances, carbonic acid and water, are definite kinds of matter ; each is characterised by properties which distinguish it from all other kinds of matter, and each is characterised by a definite and unchangeable composition.

A cup of tea is, in some respects, a definite substance with its own properties, but the composition of a cup of tea varies considerably ; sometimes milk is present, sometimes it is not, sometimes sugar is put into the tea, sometimes there is no sugar. Mortar has properties different from the properties of other things, and different from the properties of the sand, the lime, or the water, which compose it ; but it would be hard to find two specimens of mortar made up of exactly the same proportionate quantities of sand, lime, and water ; the composition of mortar may, and does, vary—within certain limits—without the occurrence of such a change in the properties of the mixture of sand, lime, and water, as compels us to say that this mixture is no longer mortar. Putty is composed of whitening and oil ; if the putty is too hard and stiff, the addition of a little oil makes it softer and more pliable ; if it is too soft, a little whitening will harden it. There are limits to the amount of oil which may be used, and there are limits to the amount of

whitening which may be used ; the putty must be stiff enough to hold together, and it must be soft enough to be easily moulded and shaped by the hand ; but very large variations in composition are allowable within these limits, without the destruction of the essential properties of putty.

Substances like a cup of tea, mortar, or putty, differ essentially from substances like carbonic acid and water :—the compositions of the former substances vary more or less, and the properties of different specimens of any of them are not quite identical ; the compositions of the latter substances do not vary in the slightest, and the properties of different specimens of any of them are absolutely identical. Moreover, the properties of a cup of tea, of mortar, or of putty, are not very different from the properties of the substances of which these things are composed ; but the properties of carbonic acid and water are entirely different from the properties of the constituents of these substances.

We have seen that the behaviour of ordinary air towards a burning taper is what we should expect the behaviour to be of a mixture of oxygen and nitrogen (*see* p. 46). So far as our examination went, we were justified in saying that common air does not differ very much from its constituents. Hence it is likely that common air will be found to resemble mortar, putty, or a cup of tea, rather than carbonic acid or water—that is, it is likely that careful examination will show the composition of air to vary somewhat, and the properties of different specimens of air to be not quite identical.

A very large number of analyses of air from different localities far from towns or villages has been made ; the result is that 100 cubic inches, or 100 cubic feet, or 100

cubic centimetres of air contain about 21 cubic inches, or 21 cubic feet, or 21 cubic centims. of oxygen, and about 79 cubic inches, &c. of nitrogen. The volume of oxygen in 100 volumes of pure country air has been found to vary from about 20.85 to about 21.0 volumes, and the volume of nitrogen to vary from about 79 to about 79.15 volumes per 100 volumes of air. This variation is not great, but it is quite sufficient to show that the composition of air is somewhat different in different localities and under different conditions. Besides oxygen and nitrogen, which are its main constituents, air contains small quantities of carbonic acid, ammonia, and water-vapour; the quantity of carbonic acid in country air is about 3 volumes per 10,000; the quantity of ammonia is about 0.1 parts per million, but it varies much; and the quantity of water-vapour varies much according to the locality and the season of the year. The air of towns contains considerable quantities of solid matters, such as soot, and various gases produced in the fires of houses and in the carrying out of manufactures. The effects of the air of different localities upon the health suffice to show that the properties of air are not always the same. If air were of constant composition and had always the same properties nothing would be gained by change of air.

Ordinary air, then, is like mortar, putty, or a cup of tea, inasmuch as its composition is not always the same and its properties vary somewhat. Water and carbonic acid, on the other hand, differ from air, mortar, putty, or a cup of tea, inasmuch as both their compositions and their properties are always the same.

Substances which vary more or less in composition and properties are called *mixtures*; substances which do not

vary either in composition or properties may be called for the present *not-mixtures*.

If a heap of gravel is shaken in a coarse sieve it is separated into two parts, one consisting of coarse particles and the other of finer grains; if the finer portion is again sifted, it can be separated into two parts differing in fineness; by repeating the process, using finer and finer sieves, the gravel may be separated into perhaps half-a-dozen portions, each more or less unlike the others. If these portions are mixed together, the original gravel is reproduced. We know that neither water nor carbonic acid can be separated into unlike parts by sifting or cutting, and that these substances are not produced by mixing their constituents, hydrogen and oxygen in one case, and carbon and oxygen in the other case. We also know that water can be separated into two things, hydrogen and oxygen, which are very unlike water, by passing an electric current through acidulated water, and we know that water can be produced by passing an electric spark through a mixture of one part by weight of hydrogen and eight parts by weight of oxygen. We also know that carbonic acid is formed by burning carbon in plenty of oxygen, and that one part by weight of carbon always combines with $2\frac{2}{3}$ parts by weight of oxygen to form $3\frac{2}{3}$ parts by weight of carbonic acid.

Let us now inquire whether the constituents of water or carbonic acid can be separated into things unlike themselves. From experiments already made (*see* experiments 13, 15, 21, pp. 22, 27, 38), it is evident that hydrogen, carbon, and oxygen, can be changed into other things. When carbon is burnt in a large quantity of oxygen, the carbon disappears, some of the oxygen also disappears, and

carbonic acid is formed; when hydrogen is burnt in a good deal of oxygen, the hydrogen and some of the oxygen disappear, and water is formed. But in none of these processes has the carbon, the oxygen, or the hydrogen been separated into things unlike itself; the new substance, carbonic acid or water, has been produced by adding oxygen to carbon, or by adding oxygen to hydrogen; all the carbon and all the oxygen used are contained in the carbonic acid; all the oxygen and all the hydrogen used are contained in the water. The proof of this statement consists in the facts, gained by carefully conducted experiments, that the weight of carbonic acid formed is exactly equal to the sum of the weights of carbon and oxygen used, that the sum of the weights of carbon and oxygen obtained from carbonic acid is equal to the weight of carbonic acid from which they are obtained; that the weight of water formed by passing an electric spark through hydrogen and oxygen is equal to the sum of the weights of hydrogen and oxygen used, and that the sum of the weights of hydrogen and oxygen obtained from water is equal to the weight of water from which they are obtained.

It is not possible for the student to verify these statements for himself at this stage of his progress; the results of the analyses and syntheses required to be made are not trustworthy unless the experimenter has considerable skill and large practice. The student must be content to accept the statements as the results of numerous quantitative experiments made by trained naturalists with the greatest care.

But there may be other processes wherein carbon, hydrogen, or oxygen is separated into unlike parts. By

what kind of processes are substances separated into their constituents?

The application of heat to a substance sometimes tears apart the things of which it is formed.

To separate sulphate of copper into water and a white solid, and to re-form the sulphate of copper.

Experiment 27.—Powder a little blue vitriol (*sulphate of copper*), place it in a thin basin or crucible, and cover the dish with a dry glass funnel; heat the blue vitriol, and stir it with a glass rod from time to time. Steam is given off and condenses on the sides of the funnel to drops of water. After heating for a time, a white powder remains in the dish. Allow to cool, and then pour *a few drops* of water on to the white powder; the water seems to be soaked up, and the white substance becomes blue.

In this experiment the blue vitriol is resolved by heat into water and a white solid, and the blue vitriol is re-formed by combining water with the white solid.*

In experiment 25 (p. 50) whitening was separated into lime and carbonic acid by heating it.

The passage of an electric current through a substance sometimes resolves it into its constituents.

To separate sulphate of copper into copper and something else by the action of an electric current.

Experiment 28.—Pass an electric current through a solution

* The student should notice that this statement is not proved by experiment 27. To prove the statement it would be necessary to prove that the weight of blue vitriol used was equal to the sum of the weights of water and white powder obtained in the first part of the experiment; and that the weight of blue vitriol obtained in the second part of the experiment was equal to the sum of the weights of water and white powder used. Here again the proof of the statement can be gained only by quantitative experiments.

of blue vitriol in water acidulated with oil of vitriol, using two fair-sized pieces of platinum as the poles or electrodes (*compare* experiment 11), and placing these in the solution of blue vitriol about $\frac{1}{2}$ inch ($1\frac{1}{4}$ centims.) apart, and *not touching one another*. When the current has passed for a little, one of the electrodes is seen to be covered with a red solid deposit.

In this experiment the blue vitriol is resolved by the electric current into copper (the red solid), and sulphuric acid which remains dissolved in the water.

A substance is sometimes separated into its constituents by the reaction with it of another substance, either with or without the aid of heat.

To separate sulphate of copper into copper and something else by the action of a piece of iron.

Experiment 29.—Make a solution of blue vitriol (sulphate of copper) in water, add a little sulphuric acid, and place a large clean knife-blade in the solution. After a few minutes the blade becomes covered with a red solid, which is copper.

In this experiment the blue vitriol is resolved, by the action of the iron upon it, into copper and sulphuric acid; the copper is deposited on the iron, and a portion of the iron is at the same time dissolved by the sulphuric acid.*

To separate chlorate of potassium into oxygen and a white solid by the action of heat and charcoal.

Experiment 30.—Place a small quantity of powdered dry *chlorate of potassium* in a dry test tube, put two or three *small* pieces of charcoal on the chlorate of potassium, and close the tube by a well-fitting cork carrying a glass tube bent round at about an angle of 45° , and passing downwards into a small beaker, in which place a little lime-water. Heat the tube until

* See note on p. 60.

the chlorate of potassium melts and gas comes off; the charcoal burns brilliantly, and the formation of white solid matter in the lime-water shows that carbonic acid gas is produced. When the charcoal is quite burnt away, allow the tube to cool, pour a little distilled water into it, and warm until some of the solid matter in the tube is dissolved. Pour out the solution into a clean tube and add to it a few drops of solution of *silver nitrate*; a white, curdy solid is formed and falls to the bottom of the tube. Now dissolve a little chlorate of potassium in warm distilled water, and add a few drops of silver nitrate solution; no visible change occurs. Therefore, when charcoal is brought into contact with molten chlorate of potassium, carbonic acid gas is formed, and there remains in the vessel a white solid which is different from potassium chlorate.

The white solid which, when dissolved in water, gives a white precipitate on addition of solution of silver nitrate, is called *chloride of potassium*. In this experiment the reaction of the carbon (charcoal) with molten chlorate of potassium resolves that substance into two unlike parts; one of these parts is chloride of potassium which remains as a white solid, the other part is oxygen which combines with the carbon to form carbonic acid gas.*

Neither by the action of heat or electricity, nor by reacting with other substances, nor by any other means, has any kind of matter been separated from carbon, hydrogen, or oxygen, unlike carbon, hydrogen, or oxygen.

* It is evident that this statement could be proved only by weighing the chlorate of potassium used, and the chloride of potassium left, and measuring the carbonic acid formed; then the quantity of oxygen in the carbonic acid produced could be found, as the composition of carbonic acid is unalterable, and is known. If the sum of the weights of potassium chloride and oxygen was equal to the weight of potassium chlorate, and if the apparatus remained unchanged in weight, the statement in the text would be proved. These quantitative experiments have been performed.

These substances have been changed ; but the changes have been proved, by carefully made quantitative experiments, to consist in the addition to the carbon, hydrogen, or oxygen of some other kind of matter ; the changes have been proved not to consist in the separation of any of these three substances into parts unlike, and each weighing less than, the original substance.

Inasmuch as carbon, hydrogen, and oxygen are definite kinds of matter, characterised by definite properties which never vary, these substances belong to the class of *not-mixtures* (see p. 58). But as carbon, hydrogen, and oxygen have not been separated into unlike parts, while water and carbonic acid have been separated into kinds of matter unlike themselves, it is evident that the class of not-mixtures must be divided into two sub-classes. Those substances which have perfectly definite and unvarying properties and compositions, and which are resolvable into constituents unlike themselves, are called *compounds*; those substances which have perfectly definite and unvarying properties, and which have not been resolved* into constituents unlike themselves are called *elements*. The composition of a compound is stated in terms of the elements of which it is composed ; the composition of an element is stated when the name of the element is uttered. So far as our knowledge goes we are obliged to regard an element as a kind of matter which is homogeneous in all its parts—that is, as a kind of matter every part of which has the

* The student should carefully notice the test of resolution of a substance ; from a determinate weight of the substance other substances unlike the original are obtained, the weight of each of these is less than the weight of the original substance resolved, and the sum of the weights of these is equal to the weight of the original substance resolved.

same properties as every other part. Although a compound is a perfectly definite substance, standing apart from all other substances, marked by its own properties, and therefore in a sense a homogeneous body, yet we know that every compound can be separated into, and can be formed by the combination of, two or more elements—that is, two or more kinds of matter which are themselves unlike the compound that is formed by their union.

In experiment 25, p. 50, whitening or chalk was separated by heat into lime and carbonic acid gas ; these constituents of chalk are different from chalk, each of them is a distinct kind or sort of matter with its own properties. But each of these constituents of chalk can itself be further separated into dissimilar portions. Lime can be separated, by the combined action of heat and electricity, into oxygen, and a yellowish-white rather soft solid called *calcium* ; neither oxygen nor calcium has been resolved into unlike portions, and neither has been built up by combining dissimilar kinds of matter. Carbonic acid, as we know, can be separated into carbon and oxygen, and can be built up by placing together carbon and oxygen under proper conditions ; neither carbon nor oxygen has been formed by bringing together two or more unlike substances, nor has either of these bodies been resolved into two or more unlike substances. A partial analysis, or resolution into its constituents, of chalk, results in showing this substance to be composed of lime and carbonic acid ; but a fuller and more searching analysis shows it to be composed of carbon, oxygen, and calcium. The compound chalk is made up of the compounds carbonic acid and lime ; but the compound carbonic acid is itself made up of the elements carbon and oxygen, and the compound lime is itself made up of the elements calcium and oxygen.

We have learnt that air is a mixture chiefly of oxygen, nitrogen, carbonic acid, ammonia, and water-vapour; of these constituents of air, oxygen and nitrogen have not been resolved into dissimilar parts, they are, therefore, put in the class of elements; carbonic acid and water are compounds, and ammonia is also a compound.

Every compound can be built up by the union of two or more elements, and also can be resolved into two or more elements; the sum of the weights of the elements into which the compound is resolved, or by the union of which the compound is formed, is equal to the weight of the compound thus resolved, or thus formed. The methods by which compounds are produced from their elements are very varied; the methods by which compounds are resolved into their elementary constituents also vary much, but most of them belong to one or other of the classes already illustrated by experiments (experiments 27 to 30, pp. 60, 61), namely, the action of heat, the action of the electric current, reaction with other bodies, or two or more of these taken conjointly.

Any definite kind of matter which has not been formed by the union of two or more unlike kinds of matter, nor has been separated into two or more unlike kinds of matter, is placed in the class of elements. A substance may be called an element to-day, and found to be a compound to-morrow. New methods for the resolution of substances into unlike portions are discovered from time to time. Until the galvanic battery was at the disposal of the chemist, lime was thought not to be resolvable into constituent parts; but since Davy obtained from lime two substances quite unlike itself, by submitting it to the action of the electric current, lime has been classed among

the compounds. Therefore, to say that this or that body is an element, is not to assert its absolute homogeneity, but merely to express the fact that the body has not been resolved into dissimilar portions.

We are now in a position to give a fairly accurate statement of the changes which take place when a candle burns in air, in terms of the language we are learning. Candle-stuff is a mixture of several compounds of the elements carbon and hydrogen, this mixture generally also contains some compounds of the elements carbon hydrogen and oxygen; when this mixture of compounds is burnt in air, which is for the most part a mixture of the elements oxygen and nitrogen (with small quantities of the compounds water, ammonia, and carbonic acid), the compounds of carbon and hydrogen, or of carbon hydrogen and oxygen, in the candle-stuff react with the oxygen in the air; the element carbon is torn away from combination with hydrogen, or hydrogen and oxygen, and enters into combination with the element oxygen, thus producing carbonic acid; the element hydrogen is torn away from the carbon, or from the carbon and oxygen, with which it was combined, and enters into combination with oxygen, thus producing the compound water:—the other constituent of the air, namely the element nitrogen, remains unchanged. If there is more air than suffices to burn all the candle-stuff, the excess of air remains also unchanged.

We start with a mixture of compounds of carbon and hydrogen (and in some case also oxygen) on the one side, and a mixture of the elements oxygen and nitrogen on the other side; we finish with a mixture of the element nitrogen with a compound of carbon and oxygen (carbonic acid) and a compound of hydrogen and oxygen (water.) Two

kinds of change occur in these processes, and both are very definite; there are definite changes of composition, and there are definite changes of properties. The compositions of different specimens of candle are not the same, nor are the compositions of different specimens of air quite identical; but the composition of each compound of which the candle-stuff is a mixture is perfectly definite and quite invariable, and the composition of each compound which is produced during the combustion of the candle is also perfectly definite and quite invariable. The properties of a tallow candle are not quite the same as those of a wax candle, nor is every portion of the same candle identical in properties with every other portion; but the properties of any specimen of any one compound present in a candle are the same as those of all other specimens of this compound, and the properties of the compounds formed by burning a candle, water and carbonic acid, never show the smallest variations.

The changes which take place when a candle burns in air are representative chemical changes. To elucidate these changes we have to inquire into the composition of the candle-stuff, and the compositions of the things that are formed when this stuff is burnt, and we have also to inquire into the composition of the air before and after the candle has burnt; this branch of the inquiry resolves itself into determining the elements which compose the compounds present in the candle, and the elements present in the air, and also the quantities of these elements contained in determinate quantities of those compounds, and in a determinate quantity of that air. And it is also necessary, in order to elucidate the changes, to inquire into the properties of the compounds of the candle, and the pro-

erties of the elements which form these compounds, and to connect the properties of the elements with the properties of the compounds which they form ; and finally it is necessary to determine the properties of the elements in the air, and to connect these properties with those of the compounds which are produced by burning the candle in the air.

Chemistry studies the properties of elements and compounds, the compositions of compounds, the connexions between the compositions and properties of compounds, and the connexions between the compositions and properties of compounds and the properties of the elements which unite to form these compounds.

In the changes of composition and properties which form part of the growth of plants we have examples of chemical occurrences. The growing plant absorbs certain definite compounds from the soil, through its roots ; it also takes in, by the leaves, certain definite substances from the air : by the mutual action of these elements and combinations of elements, under the influence of the sunshine, interchanges of elementary substances occur, and these result in the production of many compounds, by the due intermixture of which, the stem, the leaves, the tissues, and the flowers, of the plant are formed and grow. The tender greens of the early spring-time, the richer and deeper shades of green which make pleasant the long days of summer, the flaming banners, dyed in gold and russet and scarlet, wherewith autumn tries to cover the year's retreat into the dreary and colourless winter ; these all speak to the chemist of orderly and regulated change. In each stage of the yearly cycle the chemist sees the effects of unchanging laws ; he knows that these most diverse results

come from the action of a few causes which are effective in every instance ; and although he cannot foretell what forms of beauty will result from the effects of the varying conditions under which the same laws are operative, yet in all the manifold variety of the results he is able to perceive the operation of the same causes ; and this perception of unity of cause amid variety of effects is at once the end of his investigation and the recompense of his toil.

Many processes on which large manufactures are based are examples of chemical changes. A compound called *sulphur dioxide* is formed by burning the element sulphur in air ; when this compound is caused to react with another compound known as *nitrogen dioxide*—composed of the elements nitrogen and oxygen, and obtained from nitre—in presence of steam, oil of vitriol, or sulphuric acid, is produced. This acid is a compound of the elements hydrogen, oxygen, and sulphur ; the study of the relations between the composition and the properties of this acid, and the study of the relations between the composition and the properties of this acid and the properties of its elementary constituents, are chemical studies. When sulphuric acid is mixed with common salt, an acid gas is given off, and a solid substance, different from both salt and sulphuric acid, is formed ; when this solid is mixed with chalk and coal, the mixture is strongly heated, and the molten mass is allowed to cool and is then lixiviated with water, a solution is obtained, by evaporating which crystals of washing soda are formed. Analysis shows that the compositions of sulphuric acid, common salt, and washing soda are fixed and invariable ; these substances are definite compounds. The changes of composition which occur in the manufacture of soda crystals from common salt, and

the changes of properties which accompany these changes of composition, are subjects for inquiry by the chemist.

The extraction of metals from their ores, the manufacture of dye-stuffs, the preparation and purification of essential oils, the formation and the setting of mortar and cements, the processes of tanning hides and skins, the making of ink, these, and a hundred other processes, furnish examples of chemical occurrences which lie at the root of important trades. For in all these processes definite changes of composition take place, and are accompanied by definite changes of properties; elements combine in fixed quantities with other elements; determinate quantities of compounds react with determinate quantities of other compounds, the elementary constituents of compounds are rearranged in new forms of combination, and the new substances so produced have characteristic and invariable properties.

About seventy distinct kinds of matter are known at present, none of which has been separated into dissimilar portions, and none of which has been produced by putting together two or more unlike substances. By the union of these elements, seventy or so in number, all the compounds with which chemists are acquainted have been formed. These elements differ very much in their properties. Some of them, such as oxygen, hydrogen, and nitrogen, are colourless gases; a few are coloured gases—for instance, chlorine and fluorine; some are liquids, to this class belong bromine—a deep red liquid—and mercury; most are solids. All the metals belong to the class of elements, for instance, iron, zinc, lead, tin, copper, silver, gold, platinum, nickel, aluminium, and mercury; sulphur, iodine, arsenic, carbon, phosphorus, are elements.

The business of the chemist is to find out the properties of these elements, and the properties and compositions of the compounds which are formed by their union, and to generalise the results of this study into expressions of wide, and if possible universal, application.

CHAPTER IV.

THERMAL CHANGES THAT OCCUR DURING PROCESSES OF BURNING.

THE changes of composition and properties which take place when a candle, a gas-jet, a piece of wood, or a lump of coal burns, are very similar. In each case we start with a mixture of compounds of carbon and hydrogen, or of carbon, hydrogen and oxygen, and these are changed into mixtures of the compounds carbonic acid gas and water, and, in the cases of coal and wood, into solid ashes also ; oxygen is needed to effect these changes, and this oxygen is supplied by the circumambient air.

In all these burnings, heat, light, and flame are produced. In each case rapid chemical change occurs, and as long as this rapid change proceeds, we feel heat and see flame ; when the candle is extinguished, the gas turned off, the burning wood quenched, or the fire burnt out, the change of properties and composition stops, and the heat and light cease to be produced. It is as if a mill-wheel was being turned by the fall of water from a higher to a lower level ; as long as the water rushes down through the wheel, the wheel turns ; when the sluice above is closed, the fall of water ceases, and the wheel stops.

Why does heat become manifest when certain chemical processes are taking place ? Does the production of heat always accompany the re-arrangement of elements and the

breaking up of compounds? What is heat? Why is the burning of a candle, or a gas-jet, a visible event, while some chemical changes, such as the rusting of iron, or the gradual change of the food we consume into bone, blood, and muscle, do not force themselves on our sight? What is light? What is flame? The inquiries suggested by these questions are physical rather than chemical. Let a few words on these matters suffice at present.

Heat is not a kind or form of matter. All matter is ponderable; but large quantities of heat can be produced during certain material changes without any alteration in the mass of the matter undergoing change. Thus large quantities of heat are obtained when a cannon is bored; but the weight of the bored cannon, added to that of the boring apparatus and the borings, is equal to the weight of the cannon and the boring instrument at the beginning of the operation. If a paddle is rapidly rotated in water, the water becomes hot; but the weight of the whole apparatus, after much heat has been produced, and has been conducted away, is the same as the weight of the whole apparatus before the heat left it.

Although heat cannot be measured by weighing—for it is imponderable—it can be measured by finding the quantity of work it will do under defined conditions. For heat is one of the natural agents for doing work. Heat is used to drive all kinds of machinery. A head of water may be allowed to fall to a lower level without doing any work useful to man; but if a mill is built, and the falling water is made to pass through and turn the mill-wheel, this wheel causes the machinery of the mill to move, and so useful work is done, without any diminution in the quantity of water which flows down the stream

below the mill. The water flowing down hill can do something which the water cannot do as long as it remains at an unchanged level. We may compare a piece of coal before burning to the head of water above the mill-wheel; and we may liken the change from coal and air to carbonic acid, water, and nitrogen, to the fall of the water to the level of the stream below. As long as the chemical change proceeds heat is produced, and that heat can be made to do work, such as driving an engine; when the chemical change stops no more work can be done, unless, indeed, some means is found for causing the ashes to undergo another change wherein heat is produced. So when the water has reached the lower level it ceases to do work, unless it be allowed to fall farther; for during the second fall also work will be done.

There are other natural agents for doing work besides heat; these are electricity, light, bodies in motion, &c. Anything by which work can be done, but which is not itself ponderable matter, is called a form of energy. One kind of energy can be transformed into other kinds; sometimes the transformation is complete, sometimes it is not. One form of energy will do certain kinds of work which other forms of energy will not do. The sum of the various forms of energy in any portion of matter which is entirely cut off from contact, or intercommunication, with other portions of matter, is constant, and cannot be changed, although the quantity of one form may be increased while the quantity of another is decreased to a corresponding amount. We are accustomed to say that as the quantity of matter in the universe is fixed and unchangeable, although the forms of matter are very varied, and are to some extent changeable one into an-

other, so the quantity of energy in the universe is fixed and unchangeable, although the forms of energy are varied, and, within certain limits, are changeable one into another.* Of all the forms of energy heat is that into which the others are most easily and most commonly changed.

We shall see hereafter that every chemical change is accompanied by either a gain or loss of energy to the material system the composition and properties of which have changed.

Let us now turn back to consider the changes of composition which occur when a candle or a piece of coal burns. In both cases, as well as in the burning of a jet of gas or a piece of wood, rapid combination of oxygen with the elements of the burning substance takes place. The oxygen is supplied from the air; if the air is removed burning ceases. Now let the following experiment be performed:—

To burn phosphorus in oxygen supplied by the reaction of oil of vitriol with chlorate of potassium.

Experiment 31.—Place about 5 grams (75 grains) of potassium chlorate in small pieces, not in fine powder, in a narrow beaker; lay two or three *small* pieces of phosphorus on the top of the chlorate; pour in a fair amount of water; place a funnel-headed tube in the beaker with its lower end touching the chlorate of potassium, and pour five or six drops of concentrated oil of vitriol down the tube. The phosphorus takes fire, and burns under the water.†

In this burning, oxygen is supplied by the reaction

* Of course, the theoretical interpretation of both these statements depends on the meaning given to the word *universe*; but for practical purposes the meaning of the statements is sufficiently clear.

† Small quantities of material must be used in this experiment, as otherwise an explosion may occur.

between the potassium chlorate and the oil of vitriol (experiment 21 has shown us that oxygen can be obtained from potassium chlorate), and the phosphorus burns in the oxygen thus obtained. The oxygen required to burn one of the constituents of the material system—the phosphorus—is supplied by the interaction of two other constituents of the same system—the oil of vitriol and the potassium chlorate; the oxygen is not obtained from the air.

Gunpowder and guncotton are substances composed of very combustible materials in company with much oxygen, the oxygen being combined with other elements; when these substances are burnt, the oxygen required to burn the combustible materials is supplied by the substances themselves. Gunpowder is a mixture of the compound nitre (potassium nitrate) with the elements sulphur and carbon (charcoal); nitre is a compound of the elements nitrogen, potassium, and oxygen, and contains nearly 50 per cent. of oxygen; sulphur and carbon are easily burnt to sulphur dioxide gas and carbonic acid gas respectively. When gunpowder is ignited, a portion of the sulphur or carbon (or portions of both) is burnt, heat is produced, and this process suffices to start the decomposition of the nitre, whereby oxygen is produced in close contact with the combustible carbon and sulphur; the chemical change proceeds very rapidly, and as the oxygen needed is stored in the powder itself, gunpowder can be burnt in a confined space out of free contact with the air, provided the ignition of the powder has been started. Inasmuch as the products of burning sulphur and carbon are gases, these products occupy a much larger volume than the powder itself; hence the rapid burning of gun-

powder in a confined space is accompanied by an explosion.

Guncotton is a compound of the elements carbon, hydrogen, oxygen, and nitrogen, containing nearly 60 per cent. of oxygen; when ignited, guncotton is burnt wholly to gaseous substances—chiefly carbonic acid gas, steam, and nitrogen—and all the oxygen required for this process is supplied by the guncotton itself; hence the process is very rapid, and, if carried out in a confined space, it is explosive.

The three processes of burning we have been considering are essentially similar to those which take place when a candle or a jet of gas is burnt; in all of them oxygen is concerned. In the combustion of a candle or a piece of coal, the oxygen is supplied, for the most part at any rate, by the air wherein the material burns; but in the burning of phosphorus as described in experiment 31, in the burning of gunpowder, and in the burning of guncotton, the oxygen is supplied by the materials of the system which undergoes rapid chemical change.

So far, then, the characteristics of a process of combustion seem to be that a chemical change takes place rapidly, accompanied by the production of heat and light, and that the change consists in the combination of oxygen with other elements, which are generally carbon and hydrogen.

Chemical processes may occur with the accompaniment of the production of heat and light without involving the interaction of oxygen. As an illustration of such processes perform the following experiment:—

To burn copper in vapour of sulphur.

Experiment 32.—Place a considerable quantity of sulphur in

a fair-sized, round-bottomed flask ; support the flask on a thin iron tray, and heap sand round the bottom of the flask to the height of about an inch from the tray. Heat the sand-tray by a large Bunsen lamp, until the sulphur is melted and begins to boil. While the sulphur is being heated, cut some *thin* copper foil into strips, about ten or twelve inches (25 to 30 centims.) long, and $\frac{1}{4}$ inch ($\frac{1}{2}$ centim.) wide. When the sulphur has boiled for five or ten minutes, and the flask is filled with sulphur-vapour, heat the end of one of the strips of copper foil, and dip the strip into the flask till the end nearly, but not quite, touches the molten sulphur. The copper burns in the sulphur vapour and emits a bright red light. The process may be repeated with several strips of copper foil.

In this process we have a rapid combination of sulphur and copper, and this chemical change is accompanied by the production of heat and light.

The term *burning*, or *combustion*, is generally used in chemistry to include all rapidly occurring chemical changes wherein heat and light are produced, whether oxygen does or does not take part in these processes. If the combustible substance and the products of the burning are solids, these solids become so hot that they emit light, but there is no flame. If a gas is concerned in the burning, and this gas becomes so hot as to be luminous, the combustion is said to be attended with flame.

The water and carbonic acid which are formed when a common illuminant is burnt are not themselves combustible ; nor can one burn the solid ashes which fall beneath the grate wherein a fire of wood or coal is alight. But, is it possible to change the ashes back to combustible substances ? Can we unburn the burnt substances ?

This question is an important one. Consider the case of a steam-engine ; when the fuel is consumed, is there any

way of re-forming it? "It is not worth while trying," you may say, "it is easy enough to get fresh fuel." But the supply of coal and wood and oil is not inexhaustible. If all the combustible things in the world were burnt how should we be able to get heat and light?

Let us consider the ashes which are left when a candle burns. These ashes are a mixture of the compounds water and carbonic acid gas; although we cannot see these things they may nevertheless properly be called ashes, as they remain when the candle is burnt out, and they are not themselves combustible.

In experiment 11, p. 18, hydrogen and oxygen were obtained by passing an electric current through acidulated water. As water is formed by burning a mixture of hydrogen and oxygen, the process of separating acidulated water into hydrogen and oxygen, by the passage through it of an electric current, may be called *unburning* water. Now perform the following experiment:—

**To unburn water by passing water-gas over
red hot iron.**

Experiment 33.—Arrange an apparatus as shown in Fig. 17. The flask is fitted with a cork, which carries a short glass tube that passes through a good cork into a wider tube with a bulb blown on it; this bulb-tube carries a cork through which passes a delivery tube, the lower end of which dips beneath water in a small trough. Disconnect the bulb-tube by removing the cork *a*, place in the bulb about as much *very finely divided iron** as will partly fill the lower portion of the bulb; put water in the flask, and set it over a Bunsen lamp; when the water boils lower the lamp so that very gentle boiling is continued; heat the bulb for a little, then press in the cork *a*, and continue to

* Use *ferrum redactum* of the Pharmacopœia in this experiment.

heat the bulb. Heat at first gently, waving the flame about so that the bulb is equally heated, and then more strongly ; after a little the iron glows, and gas issues at the end of the tube *b*. Fill two test-tubes with water, immerse them mouth downwards in the water of the trough ; when gas has been issuing freely from *b* for a couple of minutes or so, bring one of the test-tubes over the end of the delivery tube, and keep it there until it is filled with the gas. Now place the thumb under the mouth of the tube, lift the tube out of the water, withdraw the thumb, and *at once*

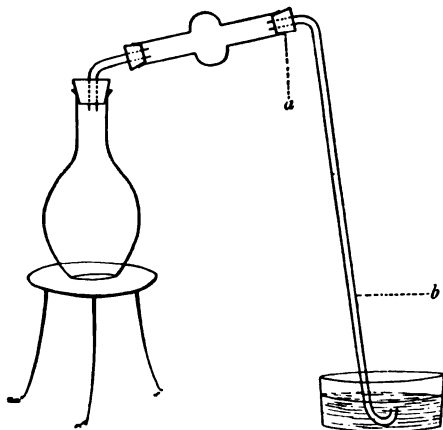


Fig. 17.

bring the tube, *still mouth downwards*, to a flame ; the gas in the tube takes fire and burns with a scarcely visible flame. Fill the other tube with the gas, turn it mouth upwards, remove the thumb, and after a minute or so bring a light to the mouth of the tube ; nothing happens, the gas is no longer in the tube.

The gas produced by passing steam over hot finely divided iron is hydrogen. *Compare experiments 13, 23, pp. 22, 40.*

Continue to pass steam over the heated iron in the bulb-tube as long as the iron glows and gas issues from the delivery tube ; from time to time gently tap the bulb-tube, so as to

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expose a fresh surface of the iron to the action of the steam. When the process is finished remove the water-trough, allow the bulb-tube to cool and examine its contents. The material in the tube is blacker than and different from the iron before steam was passed over it.

As you have found that heated iron glows in steam, and as you know that iron rusts, that is combines with oxygen, when exposed to moist air (*see* experiment 17, p. 31), moreover, as you have obtained hydrogen by passing steam over heated iron, and as you know that steam or water is composed of hydrogen and oxygen, the conclusion is reasonable that in experiment 33 the water was decomposed by the interaction between it and the hot iron, and that the oxygen of the water combined with the iron to form a compound of iron and oxygen.

To prove that the black substance obtained by passing steam over hot iron is a compound of oxygen.

Experiment 34.—Attach an apparatus wherein hydrogen can be made, *and dried*, to the bulb-tube containing the black substance produced by heating iron in steam in experiment 33; connect the other end of the bulb-tube with a small *dry* U-tube; *compare* experiment 3 (p. 5) and figure 2. Immerse the U-tube in cold water (as directed in experiment 3), and start the evolution of hydrogen. After the hydrogen has passed, in a *slow* stream, for about ten minutes, heat the bulb-tube, at first very gently, and then more strongly; maintain the passage of hydrogen for about ten or fifteen minutes; you notice that some drops of a clear colourless liquid have collected in the cold dry U-tube. Prove this liquid to be water, by determining that it boils at 100° C. or 212° F., as directed in experiment 3 (p. 6).

The result of this experiment proves that the black substance formed by passing steam over iron contains

oxygen, and confirms the conclusion already arrived at provisionally, that steam is decomposed by hot iron, the oxygen of the steam combining with the iron, and the hydrogen being given off as gas.

As water is produced by burning a mixture of hydrogen and oxygen, and as you have decomposed water by passing it, in the form of steam, over heated iron, the process which has been carried out in experiment 33 may be called unburning water.

In experiment 11 (p. 18) water was unburnt, and the constituents of the water were obtained uncombined with any other kinds of matter; in experiment 33 only one constituent of the water, the hydrogen, was obtained uncombined, the other constituent entered into union with the iron, which was the material used in effecting the process of unburning.

In one of these experiments the water was unburnt by the use of electrical energy, aided by the addition to the water of oil of vitriol; in the other experiment the water was unburnt by the use of thermal energy, aided by the interaction of iron with the water. In both cases some other kind of matter was brought into contact with the water, and in both cases energy was employed. The battery employed in experiment 11 might have been used to do some kind of mechanical work, say to drive a small engine; but that battery would do less work in driving the engine when the current was made first to pass through acidulated water and then to drive the engine, than it would do if the current was employed solely in driving the engine. So the heat from the Bunsen lamp which was used to heat the iron in experiment 33 might have been used to do the work of driving a small engine;

but the heat would do less work of this kind when part of it was used to heat the iron, than it would do if it had been employed solely in driving the engine.

In these experiments water is unburnt by bringing it into contact with some other substance, under suitable conditions, and by expending energy, or in other words, doing work, upon the water and the other substance. But when water is formed by causing hydrogen and oxygen to unite, under suitable conditions, energy becomes available for doing work. The change from hydrogen and oxygen to water can be used as a means or instrument for doing work; the change from water to hydrogen and oxygen cannot be used as a means for doing work; on the other hand, this change is not accomplished except work is done, by some suitable engine or contrivance, upon the water.

If hydrogen and oxygen were used as fuel to drive an engine, the ashes of that engine would be water; we could unburn these ashes back to hydrogen and oxygen, but only by using some other kind of engine, which in its turn would require to be fed with its appropriate fuel.

The other part of the ashes of a candle, namely carbonic acid gas, may also be unburnt to carbon and oxygen—the elements of which it is composed—under suitable and somewhat complicated conditions; in this case also it is necessary to cause an interaction to occur between the carbonic acid and some other substance, and to expend energy, or do work, upon the carbonic acid and the material with which it reacts. We shall not consider the processes which may be used for unburning carbonic acid, as they are much less simple than those whereby water is unburnt.

A partial answer has now been found to the question proposed on p. 78 as to the possibility of unburning the ashes of a candle.

The burning of the compounds of carbon, hydrogen, and oxygen which are present in a candle, to carbonic acid and water, and the unburning of these compounds to carbon, hydrogen, and oxygen, are chemical changes similar to those which were carried out with chalk in experiments 25, 26, pp. 50, 51. In one of these experiments chalk (or whitening) was resolved, or separated, into its components, carbonic acid and lime, by the application of heat; in the other experiment chalk was formed by bringing together carbonic acid and lime.

Reasoning from the analogous case of the union of hydrogen and oxygen, and the separation of water into hydrogen and oxygen, we should expect—as heat is used in separating lime from carbonic acid, in other words, as energy is spent in this process—that heat, or some other kind of energy, would become manifest when lime unites with carbonic acid to form chalk. This expectation is fulfilled. When carbonic acid gas is passed over powdered lime the two compounds combine to form chalk, and a considerable quantity of heat becomes apparent in the process. An engine might be driven by using carbonic acid and lime as fuel, but the engine would be exceedingly cumbersome and ineffective. Some form of energy must be used in making lime from chalk; this process is carried out in lime-kilns, and the separation of the lime from the carbonic acid is effected by the heat given out by burning wood or coal.

Chemical changes very similar to those which take place in making chalk from lime, and lime from chalk, occur when lime is slaked, and slaked lime is burnt.

To combine water with lime.

Experiment 35.—Place a few pieces of good lime in a basin, and sprinkle them with water, until the surface remains permanently *slightly* wet. After a few minutes the lime begins to crumble, and clouds of steam are given off. Bring the bulb of a thermometer into contact with the crumbling lime ; you notice a considerable rise of the mercury in the thermometer. When the lime has fallen to powder, place some of it in a moderate-sized *thin* basin ; warm it gently, and stir it about for a little to get it dry ; then cover the basin with an inverted dry funnel, and heat the basin, gradually raising the temperature. You notice that drops of water condense inside the funnel. Continue to heat until no water condenses on a clean *cold* funnel placed over the basin. Allow the contents of the basin to cool, and then sprinkle the lime with water ; the water is absorbed by the lime, and heat is produced, as is shown by the rise of the mercury in a thermometer placed in the lime while it is being moistened.

A definite change occurs when pure lime is slaked ; 7 lbs., or 7 ozs., or 7 grams, of lime combine with $2\frac{1}{2}$ lbs., or $2\frac{1}{2}$ ozs., or $2\frac{1}{2}$ grams, of water, and produce $9\frac{1}{2}$ lbs. &c. of slaked lime. So, when pure slaked lime is strongly heated $9\frac{1}{2}$ lbs. of it produce 7 lbs. of lime, and $2\frac{1}{2}$ lbs. of water. Similarly, when pure chalk is calcined, 14 lbs., or 14 ozs., or 14 grams, of lime and 11 lbs. &c. of carbonic acid gas are obtained from every 25 lbs. &c. of chalk ; and 25 lbs. &c. of chalk are formed by the union of 14 lbs. &c. of pure lime with 11 lbs. of carbonic acid gas. If more water than $2\frac{1}{2}$ parts by weight is added to 7 parts of pure lime, the excess of water remains unchanged ; 11 parts by weight of carbonic acid gas will combine with neither more nor less than 14 parts by weight of pure lime. Lime has its own properties which distinguish it from every other definite kind of matter ; slaked lime also has definite properties of its own.

Similarly, chalk is characterised by perfectly definite properties which belong to it, and to it only, and the properties of chalk differ much from those of either lime or carbonic acid, each of which has its own properties, and which by their union produce chalk. We have already learned that 1 part by weight of hydrogen always combines with 8 parts by weight of oxygen, and that the product is 9 parts by weight of water; and we know that each of these kinds of matter—hydrogen, oxygen, and water—is distinguished by characteristic properties which cut it off from all other kinds of matter.

The unburning of water to hydrogen and oxygen is a definite chemical change, analogous to the resolution of chalk into lime and carbonic acid, or the resolution of slaked lime into lime and water. The burning of hydrogen and oxygen to water is a definite change, analogous to the combination of lime and carbonic acid to form chalk, or the combination of lime and water to form slaked lime. The term *burning* is not generally applied to the processes wherein chalk and slaked lime are formed, because neither light nor flame is apparent in these processes; nor is the term *unburning* generally used when speaking of the resolution of chalk, or slaked lime, into its constituents. But so far as the chemical changes are concerned, the production of hydrogen and oxygen from water is very similar to the production of lime and carbonic acid from chalk, or the production of lime and water from slaked lime. There is one difference which ought to be noted; when water is unburnt, a compound is resolved or separated into its constituent elements; when chalk is decomposed by heat, or slaked lime is separated into unlike parts by heat, a compound is resolved or separated into its constituent

compounds. In one process the resolution is carried as far as it can be ; in the other processes the resolution is not complete, because the lime, the carbonic acid, and the water, are themselves compounds, and each can be separated by appropriate methods into unlike parts. The compound lime can be separated into the elements calcium and oxygen, the compound carbonic acid can be separated into the elements carbon and oxygen, and the compound water can be separated into the elements hydrogen and oxygen.

When water is formed by combining hydrogen and oxygen, when chalk is formed by combining lime and carbonic acid, when slaked lime is formed by combining lime and water, heat is produced. In each process a definite change of properties and a definite change of composition occur, and moreover, a definite quantity of heat is produced. Heat may be measured by causing it to do work, and measuring the work done. Suppose that the heat produced during the combination of hydrogen and oxygen was made to drive an engine which was used in lifting a weight from the surface of the earth against the action of the force of gravity, then one would find that the heat produced by the combination of 1 lb. of hydrogen with 8 lbs. of oxygen, to form 9 lbs. of water, would suffice to lift (in round numbers) 21,250 tons through the space of one foot.

In order to unburn 9 lbs. of water, this amount of heat must be restored ; in other words, the quantity of heat produced by the fall of 21,250 tons through one foot would just suffice to tear asunder the hydrogen and oxygen which are united in 9 lbs. of water. We have learnt (p. 73) that heat is one of several forms of energy ; a definite quantity of one form of energy is equivalent to—that is, is of equal value in exchange for—a definite quan-

tity of another form of energy. In tearing asunder the elementary constituents of water, it is easier, and more convenient, to use electrical than thermal energy, but the quantity of electrical energy used is equivalent to, and can be expressed in terms of, thermal energy. Water can be separated into hydrogen and oxygen by heat ; if drops of water are allowed to fall slowly on to a very highly heated surface, for instance on to a white hot brick, each drop of water is decomposed, or unburnt, and hydrogen and oxygen are formed.

Carbonic acid gas is produced when carbon is burnt ; 3 lbs. of carbon combine with 8 lbs. of oxygen, to form 11 lbs. of carbonic acid ; heat is produced in this process, and if the heat were caused to do mechanical work, it would be able to lift 15,000 tons (in round numbers) from the earth's surface through the space of one foot, and conversely the quantity of heat produced by the fall of 15,000 tons through one foot, or the equivalent of this quantity of thermal energy in some other form, would just suffice to unburn 11 lbs. of carbonic acid gas to 3 lbs. of carbon and 8 lbs. of oxygen, provided the energy were applied under proper conditions.

When 14 lbs. of pure lime combine with 11 lbs. of carbonic acid 25 lbs. of chalk are formed ; the heat produced in this process would suffice, if made to do mechanical work, to lift 6,600 tons (in round numbers) through the space of one foot. We know that lime is composed of the elements calcium and oxygen ; 10 parts by weight of calcium combine with 4 parts by weight of oxygen, to form 14 parts by weight of lime. Suppose we started with 10 lbs. of calcium, 4 lbs. of oxygen, and 11 lbs. of carbonic acid, caused these to combine to form

25 lbs. of chalk, and used the heat produced in driving an engine which lifted a weight; we should find that 26,900 tons were lifted through one foot. But carbonic acid can be resolved into carbon and oxygen, and 11 lbs. of carbonic acid yield 3 lbs. of carbon and 8 lbs. of oxygen. Let then an engine be driven by the heat produced in the combination of 10 lbs. of calcium with 12 lbs. of oxygen and 3 lbs. of carbon—the ashes would consist of 25 lbs. of chalk—and let the engine be made to lift a weight, the engine would lift 41,900 tons through one foot.

Conversely, the quantity of energy required to resolve 25 lbs. of chalk into 14 lbs. of lime and 11 lbs. of carbonic acid gas is equal to that amount of energy which appears in the form of heat when 6,600 tons fall through the space of one foot; the quantity of energy required to resolve 25 lbs. of chalk into 10 lbs. of calcium, 4 lbs. of oxygen, and 11 lbs. of carbonic acid gas, is equal to the quantity of energy which appears as heat when 26,900 tons fall through one foot; and the quantity of energy which is needed to tear asunder 25 lbs. of chalk into its elements—10 lbs. of calcium, 12 lbs. of oxygen, and 3 lbs. of carbon—is measured by the energy which appears as heat when 41,900 tons fall through the space of one foot.

When a process of burning takes place there are not only definite changes of composition and properties, but a definite amount of energy also changes from one form to another, and the energy, or a portion of it, generally appears in the form of heat. It is possible to collect the ashes and unburn them, and so to obtain the substances which were present when the burning began; but the

unburning can be accomplished only by the expenditure of energy, and the quantity of energy needed is equal to the energy which became apparent and available for doing work during the burning. To effect the unburning a definite quantity of energy must be used, and this energy must be applied in an appropriate way; sometimes it is applied by directly heating the ashes of the burning—for instance, water can be unburnt to hydrogen and oxygen by heat; sometimes the energy is applied in the form of an electric current—for instance, water, when mixed with oil of vitriol, is unburnt completely by the electric current; sometimes the energy is applied in the form of heat, aided by the interaction of some other substance upon the ashes to be unburnt—for instance, water is unburnt to hydrogen and oxygen, by causing steam to react with hot iron in a state of fine division; the hydrogen escapes, and the oxygen combines with the iron.

Every chemical change, whether it be called a process of burning or not, involves a definite change of composition, a definite change of properties, and a definite change in the quantity of energy in the matter whose composition and properties are changed.

The expression *changing material system* is often convenient. Take the case of the production of water from hydrogen and oxygen; at the beginning of the process the system consisted of 1 part by weight of hydrogen and 8 parts by weight of oxygen, and at the end of the process the system consisted of 9 parts by weight of water; the changing material system at one instant consisted of hydrogen and oxygen, at another instant of water, and perhaps for an inappreciably short time of hydrogen, oxygen, and water.

We may say then, in general terms, that when a material system undergoes chemical change, there occur a change of composition, a change of properties, and a change in the quantity of the energy of the system. We may expand the last part of the statement, and say, that when a chemical change occurs the changing material system either gains or loses energy. If the system gains energy, the amount gained must be supplied from outside the system. If the system loses energy, the amount lost to the system may be used in doing mechanical work, or it may spread as heat through neighbouring bodies, or it may appear as electricity, or sound, or light. As there is no loss of matter in a chemical change, as the matter only changes its forms, so there is no real loss of energy; the material system which changes properties and composition may lose energy, but what it loses some other systems gain; there may be, and there generally is, a change in the forms of energy; this change may be, and generally is, accompanied by a passage of energy from the changing material system to other portions of matter; but there is no loss in the total quantity of energy which moves from one portion of matter to another, and in its movements changes its form.

Many manufacturing operations are essentially processes of burning or unburning. As examples of processes of burning let us take the manufacture of litharge from lead, and of oil of vitriol from sulphur; and as an example of processes of unburning, let us take the manufacture of iron from the ores of this metal.

Litharge is made by spreading lead on the floor of a suitable furnace, heating the lead till it melts, and turning the charge over frequently so as to bring it into contact

with the air. The oxygen of the air combines with the molten lead, and the product is litharge.

In order to produce oil of vitriol, or sulphuric acid, sulphur is burnt in a stream of air; the burnt sulphur, called *sulphur dioxide*, thus formed is a gas; this gas is caused to mix with a small quantity of a gas obtained by heating nitric acid, called *nitrogen dioxide*, and the mixed gases are led into a large chamber made of lead. The sulphur dioxide interacts with the nitrogen dioxide and robs it of a part of its oxygen; and there are thus formed two compounds, one of which is an oxide of sulphur containing more oxygen, relatively to the same quantity of sulphur, than sulphur dioxide, and the other is an oxide of nitrogen containing less oxygen, relatively to the same quantity of nitrogen, than nitrogen dioxide. The oxide of nitrogen thus formed attracts to itself oxygen from the air in the leaden chamber, and combines with it to produce nitrogen dioxide. As a fresh quantity of sulphur dioxide comes into the chamber it withdraws oxygen from the nitrogen dioxide, and the new oxide of nitrogen thus produced again takes up oxygen from the air; these changes proceed so long as there is sulphur dioxide, nitrogen dioxide, and air, in the chamber. Steam is also sent into the chamber, and that oxide of sulphur which is relatively rich in oxygen combines with some of this steam to form sulphuric acid; the acid dissolves in the excess of steam, and this solution condenses on the floor of the leaden chamber. The acid liquor is run off and concentrated by evaporation in suitable apparatus.

As litharge is composed of the elements lead and oxygen, the process of manufacturing this compound is very simple. The change is strictly analogous to that

which occurs in burning a piece of charcoal. The burning element, lead or carbon, unites with oxygen which is present in the surrounding air, and the product is a compound of the two elements concerned in the change. In neither case does the burning take place at the ordinary temperature, but in both cases, although the process is started by heating the element to be burnt, heat is produced during the burning. Eight pounds of oxygen combine with 3 lbs. of carbon to form 11 lbs. of carbonic acid gas, and the heat produced during this change, if made to do mechanical work, would lift 15,000 tons through the space of one foot. Eight pounds of oxygen combine with $103\frac{1}{2}$ lbs. of lead to form $111\frac{1}{2}$ lbs. of litharge, or oxide of lead, and the heat produced during this change would lift 15,600 tons through one foot.

Sulphuric acid is composed of the elements sulphur, hydrogen, and oxygen; in its formation from these elements three processes of burning are concerned; hydrogen is burnt to water by combining with oxygen, sulphur is burnt by combining with oxygen, but the compound so formed does not contain sufficient oxygen, and so a second burning is accomplished wherein more oxygen is added to the product of the first burning. The second burning cannot be effected by heating the burnt sulphur in air; but it is brought about by causing the burnt sulphur to react with another compound of oxygen, and to take away oxygen from this compound. This second burning is analogous to the change which occurs when phosphorus is burnt under water, in oxygen supplied by the interaction between chlorate of potassium and sulphuric acid (*see* experiment 31, p. 75). Eight pounds of oxygen unite with 4 lbs. of sulphur and $\frac{1}{4}$ lb. of

hydrogen, to form $12\frac{1}{2}$ lbs. of sulphuric acid; the heat produced in this change, if caused to do mechanical work, would suffice to lift 14,900 tons through one foot.

The manufacture of iron from *hæmatite*, which is one of the commonly occurring ores of iron, is essentially a process of unburning. Hæmatite is a compound of iron and oxygen; it is generally mixed with varying quantities of other compounds, such as silica and lime. The essential chemical change consists in taking away the oxygen and leaving the iron.

The oxide of iron present in *hæmatite* is composed of iron and oxygen united in the proportion of $18\frac{3}{4}$ to 8. When 8 lbs. of oxygen unite with $18\frac{3}{4}$ lbs. of iron, heat is produced, the quantity being sufficient to lift about 15,000 tons through one foot. Therefore a large quantity of heat, or some other form of energy, must be used to tear away the oxygen from oxide of iron. As about 40 to 50 cwts. of iron-ore are often unburnt in a single operation, it is evident that an enormous amount of energy must be expended in carrying out the necessary chemical change. The process is conducted in the blast-furnace. The energy is obtained by burning coal or coke in the furnace, air being sent in at the bottom of the furnace. The proportion of coal and air is such that the coal is not burnt to carbonic acid, but chiefly to another compound of carbon and oxygen, called carbon monoxide, which contains half as much oxygen as carbonic acid relatively to the same quantity of carbon. This carbon monoxide, or half-burnt carbon, is completely burnt at the expense of the oxygen of the iron-ore, with the result that the iron-ore is robbed of all its oxygen, and iron remains. Two conditions are needed for the

unburning of the iron-ore ; the presence of some substance which is ready to combine with oxygen, and the presence of a quantity of energy to enable this substance to do its work. Both conditions are fulfilled in the blast-furnace.

In processes of burning, and in processes allied to these, there is always an addition to the substance burnt of some element or elements, very generally an addition of oxygen ; in processes of unburning, and in allied processes, there is a taking away of some element or elements, very generally a removal of oxygen.

Both classes of occurrences are perfectly definite ; there are always definite changes of composition, and definite changes of properties. And there are also definite changes in the distribution and forms of energy ; in the changes which are classed together as burnings, energy, as a rule, leaves the changing system, and some of this energy makes its appearance as heat ; in processes which are classed as unburnings, energy, as a rule, must be supplied to carry on the changes, and this energy is frequently supplied in the form of thermal energy, and sometimes in the form of electrical energy.

A distinction may be drawn, broadly and in the main, between animals and plants considered as machines for carrying on chemical processes. It may be said with sufficient accuracy, that, looked at in a general way, animals carry on processes of burning wherein energy is made available for doing work, and plants are instrumental in bringing about processes of unburning wherein energy is used, and stored in the plants. Animals, as a whole, are burners and thereby energy-producers ; plants are unburners and thereby energy-storers.

The growing plant absorbs carbonic acid from the air, water from the air and the earth, and ammonia and various other compounds from both earth and air ; it separates or unburns the carbonic acid, water, ammonia, and some of the other compounds which it absorbs, and with the elements thus obtained it builds up its leaves, and stem, and tissues. The animal feeds upon the materials which the plant has built up from the elements it has separated and sifted from the carbonic acid, water, ammonia, and other compounds given to it by the earth and the air ; the animal breathes in air which contains uncombined oxygen, it combines this oxygen with the food it has eaten, a process of burning takes place, the animal machine is kept going, and part of the ashes of this burning—carbonic acid and water—are exhaled by the lungs and skin into the surrounding atmosphere.

The plant is not wholly a separator or unburner of compounds, nor is the animal solely engaged in burning the substances which the plant has produced ; the plant, like the animal, carries on processes of combustion ; the animal, like the plant, is a builder up of tissue ; and both animal and plant perform many actions which do not belong to those we are now engaged in studying. Nevertheless, the distinction which the chemist draws between the plant and the animal is on the whole a just and well-founded distinction.

A plant can perform its function of unburning carbonic acid, water, ammonia, and other compounds, only when it is helped by energy. The plant grows well, and lives healthily, only in the sunlight ; the source of the energy which the plant uses, and stores in the compounds it forms in its tissues, is the sun.

The energy comes from the sun to the plant in the form of radiant heat and light ; this energy is used by the plant, and it is stored in the plant's stem, and leaves, and tissues, in the form of chemical energy ; that is, it is associated with and locked up in the compounds which the plant elaborates from the food—chiefly carbonic acid, water, ammonia, and certain mineral salts—which it absorbs from the earth and the air. We may liken the plant to an engine used to lift water from a river to a mill-race higher than the river, where the water is shut off by a sluice from descending to the river ; and we may compare the animal to an apparatus for opening the sluice, and allowing the water to flow down through the mill-wheel which is thereby turned round.

The illustration would be more complete could we suppose the liquid which the plant is employed in raising to a higher level not to be water before it is raised, but water when it reaches the level of the mill-race, and to be changed back to the liquid which is not water during its passage through the mill-wheel. The engine which lifts and in lifting changes the composition of the liquid that will afterwards be used in driving the mill-wheel, is worked by the sun.

The work which the sun does on the growing plant remains in the plant as the power of doing work ; it may remain there for a short time, or in some cases it may remain for ten thousand or ten hundred thousand years ; some day the power of doing work is changed into work actually done.

The plant may die and decay as soon as it reaches maturity, and be transformed back to carbonic acid, water, ammonia, and other compounds, from which it was elaborated ; or the mature plant may die and be buried in

the earth, so that it suffers a slow process of change extending over many ages, whereby most of the elementary constituents of the dead plant are eliminated, but the carbon, and perhaps some of the hydrogen, remains; and when the ages have past, the carbon may be dug from the earth in the form of coal, and burnt on the hearth to give warmth, or in the engine to do useful work, or in the reducing furnace to convert metallic ores into metals, wherewith instruments are fashioned for furthering the work of the craftsman.

As the storage of the sun's energy in the plant was accompanied by various changes of composition and various changes of properties, all of which changes were perfectly definite, and which were exactly the same in all cases wherein the antecedents were exactly the same, so when the energy again becomes work done the change from the power of doing work to actual work is accompanied by changes of composition and properties which are definite, and are subject to the law that the same causes produce the same results.

Let us suppose that a growing plant many ages ago breathed in 11 grains of carbonic acid gas; with the energy which came to it in the sunlight the plant separated this carbonic acid into carbon and oxygen; to do this the plant used a quantity of energy equivalent to the quantity of heat which is produced in the fall of $2\frac{1}{10}$ tons (in round numbers) through the space of one foot; the carbon thus separated weighed 3 grains, and the oxygen, most of which was sent back by the plant into the air, weighed 8 grains. Let us suppose that the plant grew for many years until it attained a great size, when it was broken down by a hurricane and buried beneath a deposit of sand and mud; slowly the

plant suffered change; after almost innumerable centuries had passed the plant had become a mass of coal, and the 3 grains of carbon, separated so long ago by the living plant from the 11 grains of carbonic acid which it absorbed from the air, were present in this coal. The coal was dug from the earth, and was burnt on the hearth; during that burning the 3 grains of carbon, which we have traced, entered into union with 8 grains of oxygen; and in this process heat was produced sufficient to lift a weight of $2\frac{1}{10}$ tons through one foot, and 11 grains of carbonic acid were formed and sent into the atmosphere.

Or, let us suppose that it was only yesterday when a growing plant absorbed from the air 11 grains of carbonic acid gas, and that to-day this plant was eaten by an animal. The 3 grains of carbon which the plant had elaborated into tissue, after tearing them away from their union with 8 grains of oxygen, entered into the system of the animal, and remained there, combined with other elements, forming a part of the flesh of the living creature. Let us suppose that to-morrow this animal dies, and that its body slowly decays; the flesh gradually putrefies; it is seized on by myriads of minute organisms, some of which break it up into exceedingly small pieces, that are laid hold of by other organisms whose function it is to act as carriers of oxygen from the air to the putrefying flesh, and to change it into carbonic acid, water, and ammonia. The 3 grains of carbon we are tracing are slowly burnt by the agency of these minute but most active scavengers; the result of that burning is 11 grains of carbonic acid; 8 grains of oxygen are used in the burning, and the quantity of heat which is produced, but produced so slowly that at no time does the temperature rise perceptibly, is exactly

equivalent to, or is of equal value in exchange for, the quantity of energy which the plant obtained from the sun, and used in separating these 3 grains of carbon from the 8 grains of oxygen with which they were accompanied when the plant absorbed them from the atmosphere. Had the energy which the plant used been converted into heat, it would have sufficed to lift $2\frac{1}{10}$ tons through 1 foot; the energy is converted into heat when the 3 grains of carbon, stored in the plant's tissues in combination with other elements, and then taken into the body of the animal, are burnt to 11 grains of carbonic acid, by the minute organisms which bring about the slow combustion of the decaying flesh of the animal; and the heat produced in that burning would suffice to raise a weight of $2\frac{1}{10}$ tons through the space of one foot.

Or we may suppose that the animal which consumed the substances the plant had built up by the help of the energy of the sun continues to live; the animal consumes the food it has eaten, and in so doing it breathes in 8 grains of oxygen from the air, and by means of this oxygen it burns the 3 grains of carbon to 11 grains of carbonic acid which it restores to the atmosphere in its exhaled breath; heat is produced during this combustion; that heat is used in carrying on the functions of the animal mechanism; had it been employed in driving an engine it would have enabled that engine to lift $2\frac{1}{10}$ tons to the height of one foot from the surface of the earth.

The source of the energy which plants store in the compounds they elaborate from their food is the sun. The sun may be regarded as a vast source of energy. But why does the sun distribute energy through the solar system? Is the solar energy the accompaniment of

chemical changes which are similar to the processes of burning that occur on the earth? Is the sun a vast fire? If the energy which radiates from the sun is connected with changes that are of the nature of combustion, is it not likely that some day the great fire will be burnt out, and no more energy will reach the worlds which the sun now sustains? If the sun is a vast fire, what fuel does this fire consume, and from whence does that fuel come?

These questions cannot be dealt with here. To attempt to gain even superficial answers would lead us away from the proper subject of our inquiry. The questions are propounded to remind the student that there is no finality in the study of nature; that the results of one inquiry lead to another investigation; that the various branches of natural science merge one into another, for the object of them all is the same, to "see things as they are," and in nature there are no boundary lines; and that an attempt to answer the questions suggested by the fire on the hearth carries the inquirer beyond the earth, and leads him as far as the material universe extends, and leaves him with his sense of wonder widened, his admiration quickened, and his reverence made more real. The words of one of our poets are literally true,—

"Flower in the crannied wall,
I pluck you out of the crannies;—
Hold you here, root and all, in my hand,
Little flower—but if I could understand
What you are, root and all, and all in all,
I should know what God and man is."

We have advanced a step farther in our examination of the changes that take place when a combustible substance is burnt. In these changes we see a compound, or a

mixture of compounds, undergoing a change of composition and properties ; the change of composition frequently, but not always, consisting broadly in the combination of oxygen with the elementary constituents of the burning substance ; and the change of properties consisting broadly in the production of ashes—or substances that cannot be burnt—from combustible material. Accompanying these changes of composition and properties, we notice that there is always a change in the form and distribution of the energy of the changing system ; and that this change, for the most part, is in the direction that energy appears in the form of heat, which may be caused to do mechanical work, and that the quantity of energy in the system is less after the change of composition and properties is accomplished than it was before that change began. And, finally, we notice that as the change of composition is definite, and the change of properties is definite, so the change in the form and distribution of energy is definite also.

CHAPTER V.

THE COMPOSITION OF COMPOUNDS.

A PROCESS of combustion, whether it proceeds in the presence of oxygen or not, is a chemical action, and is not to be separated from other chemical actions, except for convenience, in order that by studying actions which have the common feature of forcing themselves on our attention by their visible accompaniments we may arrive at a knowledge of the essential characteristics of all chemical actions.

There are many different forms or kinds of matter in the world, and these are mutually changeable within certain limits. These myriad kinds of matter seem to be built up of a few primary kinds, which are not mutually changeable, so far as we can tell; those few kinds of matter which we have not succeeded in changing one into another, and from none of which we have been able to separate portions unlike the whole, we call elements; the kinds of matter which we know to be produced by the joining together of definite quantities of elements, and each of which has always the same composition and the same properties, we call compounds. The kinds of matter we call elements may themselves be composed of unlike parts, but until we have actually separated a definite kind of matter into portions, unlike each other, and unlike the matter from which they were obtained, we

call that definite kind of matter an element. Compounds are just as definite kinds or forms of matter as elements are ; each compound has its own properties which distinguish it from all other compounds and from all elements ; but we have separated compounds, and we have not separated elements, into dissimilar portions. Chemical action consists in rearrangements of elements to form various compounds. When a chemical action takes place the quantity of matter which undergoes a change of composition and properties suffers no change ; the sum of the quantities of the various kinds of matter which form the changing system before the change begins is equal to the sum of the quantities of the various kinds of matter which form the system when the change is completed. Although energy changes its form and its distribution during a definite change of properties and composition, nevertheless the total quantity of energy suffers no change. The energy may become less available, or more available, for doing work ; some of it may leave the changing material system, or energy may enter that system ; but as there is no loss of matter, so there is no loss of energy. The statement that there is no loss of energy as there is no loss of matter is true ; but in applying it we need only consider the system which actually undergoes change, so far as the matter is concerned ; while, as concerns the energy, we must consider other systems also, because energy may leave or enter the system whose changes of composition and properties we are specially studying.

In studying chemical actions, then, we have to study the compositions of compounds, and the properties of elements and compounds, and we have to pay attention to changes in the distribution, and in the forms, of energy.

The composition of a compound expresses the quantities of the elements that are combined together in a definite quantity of the compound.

The properties of a compound include statements of the chemical actions which it undergoes under defined conditions.

We have already considered the simpler generalisations which express the connexions between chemical action and changes of energy. Let us now make an examination of the compositions of compounds, with the object of expressing the results of this examination in statements of universal applicability.

To state the compositions of compounds in parts by weight of each elementary constituent in 100 parts of each compound could not, alone, be of much service.

Consider how enormous is the possible variety of compounds which could be formed by the combinations of seventy elements. If the whole population of the world were to deal cards for playing whist for a hundred million years, they would not have exhausted one one-hundred-thousandth part of the possible deals. The chemist's pack contains 70 cards at least; how many different deals may he make?

The results of very many accurate analyses of compounds have enabled the facts regarding the gravimetric composition of compounds to be stated in three generalisations, which are of universal application and are rigidly exact. These three generalisations are usually known as the *laws of chemical combination*.

The first law, or the LAW OF CONSTANT PROPORTIONS, states that

*The masses of the constituent elements of every compound bear an unalterable ratio to each other, and also to the mass of the compound formed.**

This law asserts that the composition of every compound is always exactly the same. The law has been very carefully tested by analysing specimens of the same compounds prepared by different methods. There can be no doubt as to the rigid accuracy of the law.†

It often happens that two elements combine to form more than one compound. Thus iron and oxygen form three distinct compounds; copper and oxygen form two compounds; lead and oxygen form four compounds; carbon and oxygen form two compounds; sulphur and oxygen form at least two compounds; and so on. Let us take the two compounds of carbon and oxygen; the compositions of these compounds, in parts by weight of each element per 100 parts by weight of the compound, are as follows:—

I.	II.
Carbon = 42·85	Carbon = 27·27
Oxygen = 57·15	Oxygen = 72·73
100·00	100·00

These numbers may be stated in other forms; suppose we express the quantity of oxygen, by weight, which is combined with one part by weight of carbon in each compound; the statements are—

I.	II.
Carbon 1·00	Carbon 1·00
Oxygen 1·33	Oxygen 2·66

* The term *mass* is used as synonymous with *quantity by weight*.

† The student should read pp. 54-56, and 85-86, in connexion with this law.

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The masses of oxygen which are combined with one and the same mass of carbon in these two compounds are as 1 : 2.

The elements carbon and hydrogen combine together in many proportions to form numerous compounds; let us select four of these compounds, and state their compositions in parts per 100—

	I.	II.	III.	IV.
Carbon =	92·3	85·7	80·0	75·0
Hydrogen =	7·7	14·3	20·0	25·0
	100·0	100·0	100·0	100·0

Now let us state the compositions of these compounds as parts by weight of hydrogen combined, in each case, with one part of carbon; the statements are—

	I.	II.	III.	IV.
Carbon =	1·0	1·0	1·0	1·0
Hydrogen =	·083	·166	·249	·332

These numbers may be stated in a slightly different form, thus—

	I.	II.	III.	IV.
Carbon	1·0	1·0	1·0	1·0
Hydrogen	·083	·083 × 2	·083 × 3	·083 × 4

The masses of hydrogen which are combined with one and the same mass of carbon in these four compounds are as 1 : 2 : 3 : 4.

Five compounds of the elements oxygen and nitrogen are known; if the composition of each is stated as parts by weight of oxygen combined with one part by weight of nitrogen, we have these numbers—

	I.	II.	III.	IV.	V.
Nitrogen	1·0	1·0	1·0	1·0	1·0
Oxygen	·57	·57 × 2	·57 × 3	·57 × 4	·57 × 5

The masses of oxygen which are combined with one and the same mass of nitrogen in these five compounds are as 1 : 2 : 3 : 4 : 5.

The examination of the compositions of the three compounds of iron and oxygen gives this result—

	I.	II.	III.
Iron	1'0	1'0	1'0
Oxygen	'2857	'3809	'4286

The masses of oxygen which are combined with one and the same mass of iron in these three compounds are as 1 : 1'33 : 1'5 = 6 : 8 : 9.

The four compounds of lead and oxygen are composed of these two elements united in the following proportions—

	I.	II.	III.	IV.
Lead	1'0	1'0	1'0	1'0
Oxygen	'077	'103	'116	'154

The masses of oxygen which are combined with one and the same mass of lead in these four compounds are as 1 : 1'33 : 1'5 : 2 = 6 : 8 : 9 : 12.

The compositions of compounds formed of the same two elements are generalised in the LAW OF MULTIPLE PROPORTIONS, which states that

When two elements combine with one another to form more than one compound, the masses of one of the elements which combine with a constant mass of the other element bear a simple relation to each other.

Can a generalisation be made concerning the compositions of the compounds of one element with several others, and the compounds which these other elements form among themselves?

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If the compositions of the compounds of phosphorus and hydrogen, oxygen and hydrogen, sulphur and hydrogen, and chlorine and hydrogen, are stated in terms of one part by weight of hydrogen in each case, we have these numbers—

I.	II.	III.	IV.
Hydrogen 1·0	Hydrogen 1·0	Hydrogen 1·0	Hydrogen 1·0
Phosphorus 10·3	Oxygen 8·0	Sulphur 16·0	Chlorine 35·5

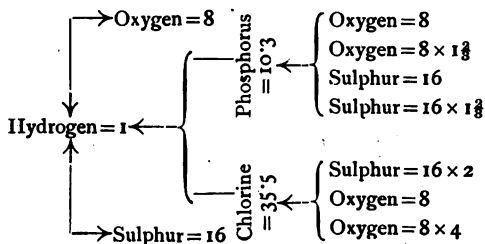
The masses of phosphorus, oxygen, sulphur, and chlorine, which, severally, combine with one and the same mass of hydrogen in these four compounds are as 10·3 : 8 : 16 : 35·5.

Phosphorus forms two compounds with oxygen, and two compounds with sulphur; chlorine forms two compounds with oxygen; and chlorine and sulphur combine to form a compound. Let us state the compositions of the compounds of phosphorus and oxygen, and of phosphorus and sulphur, so as to show the parts by weight of oxygen, and sulphur, respectively, combined with 10·3 parts by weight of phosphorus: let us state the compositions of the compounds of chlorine and oxygen so as to show the parts by weight of oxygen combined with 35·5 parts by weight of chlorine; and the composition of the compound of chlorine and sulphur so as to show the parts by weight of sulphur combined with 35·5 parts by weight of chlorine. The results are as follows—

I.			II.		
	(1)	(2)		(1)	(2)
Phosphorus	10·3	10·3	Phosphorus	10·3	10·3
Oxygen	8·0	$13·33 = 8 \times 1\frac{2}{3}$	Sulphur	16·0	$26·66 = 16 \times 1\frac{2}{3}$
III.			IV.		
	(1)	(2)		(1)	(2)
Chlorine	35·5	35·5	Chlorine	35·5	
Oxygen	8·0	$32·0 = 8 \times 4$	Sulphur	32·0	16×2

Consider the compounds which oxygen forms with phosphorus and chlorine respectively: call the mass of phosphorus which combines with unit mass of hydrogen *the fixed mass of phosphorus*, and call the mass of chlorine which combines with unit mass of hydrogen *the fixed mass of chlorine*; then the masses of oxygen which combine with this fixed mass of phosphorus and this fixed mass of chlorine, respectively, bear a simple relation to each other which is expressed by the ratio $8 : 8 \times 1\frac{2}{3} : 8 : 8 \times 4$. Now, consider the compounds of sulphur and phosphorus, and the compound of sulphur and chlorine; using the expressions *the fixed mass of phosphorus* and *the fixed mass of chlorine* with the same meanings as before: it is evident that the masses of sulphur which combine with this fixed mass of phosphorus and this fixed mass of chlorine, respectively, bear a simple relation to each other, and that relation is expressed by the ratio $16 : 16 \times 1\frac{2}{3} : 16 \times 2$.

These results are represented graphically in the accompanying diagram: the arrows indicate the elements between which combination occurs—



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The examination of the compositions of the compounds which the elements form by combining with each other leads to results similar to those we have obtained by examining some of the compounds of phosphorus, sulphur, oxygen, and chlorine. The results are generalised in the LAW OF RECIPROCAL PROPORTIONS, which states that

The masses of different elements which severally combine with one and the same mass of another element are also the masses of those different elements which combine with each other, or they bear a simple relation to these masses.

In using the law of reciprocal proportions to express the compositions of compounds, one element is selected as a standard, and one part by weight of this element is called *the unit mass of the standard element*, then the masses of the other elements which combine with unit mass of the standard element are also the masses of these elements which combine with each other, or they bear a simple relation to the masses which so combine.

Hydrogen is chosen as the standard element, inasmuch as it is lighter, bulk for bulk, than any other element. Let us call the mass, or quantity by weight, of an element which combines with unit mass, or one part by weight, of hydrogen, the *combining weight* of that element. As only a few elements combine with hydrogen, the combining weights of only a few elements can be determined by finding the compositions of their compounds with hydrogen, but all the elements except two combine with oxygen, and those two which do not combine with oxygen combine with chlorine. Inasmuch as eight parts of oxygen, and 35.5 parts by weight of chlorine, severally combine with one part by weight of hydrogen, we may use these quantities

—8 and 35·5—as standard masses of oxygen and chlorine, respectively, to which the masses of other elements that combine may be referred. We may now extend the connotation of the term combining weight, and take it to mean, the quantity by weight of an element which combines with one part by weight of hydrogen, or with eight parts by weight of oxygen, or with 35·5 parts by weight of chlorine. The law of reciprocal proportions may now be paraphrased thus—

The elements unite in the ratios of their combining weights, or in ratios which bear a simple relation to these.

The compositions of the compounds we have been examining would be expressed in ratios of combining weights as follows—

Phosphorus and Oxygen.

- (1.) One combining weight of phosphorus = (10·3) with
1 combining weight of oxygen = (8)
- (2.) One combining weight of phosphorus = (10·3) with
 $1\frac{2}{3}$ combining weights of oxygen = (13·33)

Phosphorus and Sulphur.

- (1.) One combining weight of phosphorus = (10·3) with
1 combining weight of sulphur = (16)
- (2.) One combining weight of phosphorus = (10·3) with
 $1\frac{2}{3}$ combining weights of sulphur = (26·66)

Chlorine and Oxygen.

- (1.) One combining weight of chlorine = (35·5) with 1
combining weight of oxygen = (8)
- (2.) One combining weight of chlorine = (35·5) with 4
combining weights of oxygen = (32)

Chlorine and Sulphur.

One combining weight of chlorine = (35·5) with 2 combining weights of sulphur = (32)

Now if we multiply the combining weight of phosphorus by 3 ($10\cdot3 \times 3 = 31$), that of oxygen by 2 ($8 \times 2 = 16$), and that of sulphur by 2 ($16 \times 2 = 32$), and call the quantities thus obtained the combining weights of phosphorus, oxygen, and sulphur, we can express the compositions of the above compounds in whole numbers of combining weights of their constituent elements. Thus—

Phosphorus and Oxygen.

- (1.) Two combining weights of phosphorus = (62) with 3 combining weights of oxygen = (48)

$$\text{The ratio } 62 : 48 = 10\cdot3 : 8$$

- (2.) Two combining weights of phosphorus = (62) with 5 combining weights of oxygen = (80)

$$62 : 80 = 10\cdot3 : 13\cdot33$$

Phosphorus and Sulphur.

- (1.) Two combining weights of phosphorus = (62) with 3 combining weights of sulphur = (96)

$$62 : 96 = 10\cdot3 : 16$$

- (2.) Two combining weights of phosphorus = (62) with 5 combining weights of sulphur = (160)

$$62 : 160 = 10\cdot3 : 26\cdot66$$

Chlorine and Oxygen.

- (1.) Two combining weights of chlorine = (71) with 1 combining weight of oxygen = (16)

$$71 : 16 = 35\cdot5 : 8$$

- (2.) One combining weight of chlorine = (35·5), with 2 combining weights of oxygen = (32)

Chlorine and Sulphur.

One combining weight of chlorine = (35.5), with
1 combining weight of sulphur = (32)

By widening the meaning of the term combining weight it is possible to express the compositions of compounds so that every compound is represented as made up of a small, but whole, number of combining weights of each of its constituent elements. To do this it is necessary in some cases to take the combining weight of an element as equal to the largest quantity by weight of that element which combines with one part by weight of hydrogen, with 16 parts of oxygen, or with 35.5 parts of chlorine, sometimes as equal to twice this quantity, and in a few cases as equal to three times the largest quantity by weight that combines with one part by weight of hydrogen, with sixteen parts of oxygen, or with 35.5 parts of chlorine.

The meaning to be given to the term combining weight then is as follows—

The combining weight of an element expresses either the largest mass of that element which combines with one part by weight of hydrogen, or with 16 parts by weight of oxygen, or with 35.5 parts by weight of chlorine, or it expresses a whole multiple of that mass.

The law of reciprocal proportions may now take this form—

The elements combine in the ratios of their combining weights, or in ratios which are whole multiples of these.

The law as thus expressed includes the law of constant proportions, and also the law of multiple proportions.

The three laws of chemical combination rest on and pre-suppose the truth of the generalisation which has been insisted upon more than once in this book, that whatever changes we may accomplish in the form of matter, we cannot change the quantity or mass of matter which takes part in these changes. This statement, put in various forms, is known as *the law of the conservation of matter*, or *the law of the conservation of mass*.

The laws of chemical combination have been tested by very rigorous and searching experiments; they are perfectly accurate statements which hold good, without any qualification, in all chemical changes.

A system of representing the compositions of compounds is based on the laws of combination. A symbol is given to each element, generally the first letter, or the first and another letter, of the name; the symbol stands for the element and for that quantity of it which is its combining weight. Thus O means 16 parts by weight, or one combining weight (as that term is explained on p. 114), of oxygen; P means 31 parts by weight, or one combining weight, of phosphorus, and so on. The composition of a compound is expressed in a symbol, or formula, which tells the number of combining weights of each element which are combined together to form the quantity of the compound expressed by the formula. The symbols of the elementary constituents are put together, and a small figure, expressing the number of combining weights, is attached to the symbol of each element. Thus the formula CO_2 expresses the composition of carbonic acid gas, and H_2O expresses the composition of water; the formula CO_2 tells that the compound formulated is composed of carbon and oxygen united in the proportion

of one combining weight of the former to two combining weights of the latter element; the formula H_2O tells that water is composed of hydrogen and oxygen united in the proportion of two combining weights of hydrogen to one combining weight of oxygen. Formulæ also express the compositions of compounds in parts by weight of each element in the weights of the compounds represented by their formulæ; thus, as the combining weight of carbon is 12, and that of oxygen is 16, while the combining weight of hydrogen is 1, the formula CO_2 tells that $12 + (2 \times 16) = 44$ parts by weight of carbonic acid gas are composed of 12 parts by weight of carbon and 32 parts of oxygen: and the formula H_2O tells that $2 + 16 = 18$ parts by weight of water are composed of 2 parts of hydrogen and 16 parts of oxygen. It is evident that the quantity by weight of each element in 100 parts by weight of either of these compounds, that is, the percentage composition of either compound, can be calculated from the formula; thus the percentage composition of carbonic acid gas is given by working out the equations—

$$\text{Percentage of carbon} = \frac{12 \times 100}{44}$$

$$\text{Percentage of oxygen} = \frac{32 \times 100}{44}$$

The changes of composition which take place in chemical processes are expressed by writing the formulæ of the compounds, or elements, which form the changing system at the beginning of the process to the left of the sign of equality, and the formulæ of the compounds, or elements, which form the changing system at the end of

the process to the right of the same sign. In such *chemical equations* the sign + is taken as meaning *reacts with*. Thus, when iron reacts with steam, the products of the reaction are a compound of iron and oxygen called magnetic oxide, or black oxide, of iron, and hydrogen (see experiment 33, p. 79). Quantitative experiments have shown that the masses of iron and steam which react are in the proportion of 21 : 9, and that the masses of oxide of iron and hydrogen which are formed are produced in the ratio of 29 : 1 ; these are the smallest whole numbers in which the ratios of the masses of the constituents of the changing system can be expressed. The composition of the magnetic oxide of iron is 21 of iron to 8 of oxygen, using the smallest possible whole numbers to express the proportion. Now the combining weight of iron is 56, and the combining weights of oxygen and hydrogen are 16 and 1, respectively. The simplest formula that can be given to magnetic oxide of iron, if whole numbers of combining weights of its elements are used, is Fe_3O_4 :

$$56 \times 3 = 168, 16 \times 4 = 64 ; 168 : 64 = 21 : 8.$$

If these facts and considerations are all taken into account, it is found that the simplest expression for the changes of composition that occur in this process is $3\text{Fe} + 4\text{H}_2\text{O} = \text{Fe}_3\text{O}_4 + 8\text{H}$. The larger figure multiplies the whole symbol to which it is prefixed. If this chemical equation is expressed in words and figures it reads thus ; $3 \times 56 = 168$ parts by weight of iron react with $4 \times (2 + 16) = 72$ parts by weight of water, and the products are $(3 \times 56) + (4 \times 16) = 232$ parts by weight of a certain compound of iron and oxygen—which is made up of iron and oxygen united in the proportion of 3 combining weights of iron (or 168 parts by weight of iron) to 4 combining

weights (or 64 parts by weight) of oxygen—and $8 \times 1 = 8$ parts by weight of hydrogen.

In using formulæ it is necessary to have at hand a table giving the symbols and combining weights of the elements; such a table is given in the appendix (p. 157).

In this chemical process, as in all chemical processes, there is a re-arrangement of the elementary constituents of the compounds taking part in the process; the total quantity of matter on one side of the sign of equality is equal to the total quantity of matter on the other side of the sign.

The consideration of the compositions of compounds leads to the recognition that chemical combination takes place between fixed masses of the elements; it leads us to regard the chemical reactions of elements as occurring between 1, 2, 3, 4— n little parcels of one element (n being always a whole number), and 1, 2, 3, 4— n little parcels of other elements, where the mass of every little parcel of the same element is always the same, but is always different from the mass of any little parcel of another element.

We naturally ask—Why do the elements react with one another as if each were made up of small particles all stamped with the same weight?

The molecular and atomic theory gives an answer to this question. And the answer is: because both elements and compounds are composed of minute particles or grains; because each particle of an element or compound has the properties of that element or compound; because any particle of an element or compound has the same mass as any other particle of the same element or compound, but a different mass from that of the particle of any other element or compound; and because chemical

change consists in the separation and re-arrangement of these minute particles.

Many properties of matter are inexplicable unless we recognise that matter has a grained structure; in other words, unless we admit that a piece of matter—say a drop of water—is built up of a vast number of minute grains, all to some degree separate from each other and not continuously merging into each other. Granting that matter has a grained structure, the theory goes on to define the grain or particle of any definite kind of matter—that is, of any element or compound—as the smallest portion thereof which has the properties of the kind of matter in question; it does not assert that this minute particle is indivisible, but that if it were divided some new kind or kinds of matter would result. Take for instance a drop of pure water; the molecular and atomic theory says that, if we had fine enough instruments and if our senses were sufficiently acute, we might divide that drop by cutting and sifting until at last we reached the smallest particle of the kind of matter we call water, and that were we able to divide that particle, the parts of it would not be water, but they would be other forms of matter with properties different from those of water. And the theory also says that when water is changed into hydrogen and oxygen, as is done by mixing water with oil of vitriol and passing an electric current through the mixture, a separation of the ultimate particles of water is effected and some of the parts of these particles present the properties which we associate with the thing we call hydrogen, while other parts of the ultimate particles of water present the properties of the thing we call oxygen.

The smallest particles of an element or compound

wherein the properties of that element or compound inhere are called *molecules*; when a molecule is separated into parts, these parts are called *atoms*.

According to the molecular and atomic theory, chemical change consists either in the combination of molecules with molecules to form new, more complex, molecules, or more generally, in the separation of molecules into atoms, and the re-arrangement of these atoms with the production of new molecules. Consider the formation of water by the passage of an electric spark through a mixture of 2 volumes of hydrogen and 1 volume of oxygen. The picture which the theory presents to us of this process consists of two portions: we see a vast number of extremely minute particles, or molecules, of hydrogen moving among half as many extremely minute particles, or molecules, of oxygen; as the spark passes we see the molecules of hydrogen separating each into two parts or atoms, and the molecules of oxygen separating each into two atoms; and at the same moment we see every two atoms of hydrogen laying hold of, and coalescing with, one atom of oxygen, and we see that the product of this union is a molecule of water.

A difficulty here presents itself: if the molecule is defined to be the smallest particle of an element or compound which exhibits the properties of that substance, a molecule of hydrogen is the smallest particle of a certain kind of matter which is possessed of the properties of that matter; but it has been said that the theory represents the passage of the spark through a mixture of hydrogen and oxygen as bringing about the separation of these smallest particles of hydrogen into yet smaller particles, which we call atoms of *hydrogen*. If the molecule is the limit reached in the division of hydrogen, and if the separation of a

molecule into parts is accompanied by the production of some substance with properties different from those of the molecule, and this has been asserted to be the case, then the parts of a molecule of hydrogen should not be called *atoms of hydrogen*, for they are not hydrogen at all.

The theory evades this difficulty by saying that all the parts, or atoms, of the molecule of an element are identical in mass and properties, and that although the properties of the atoms of an element are not the same as, yet they are not very different from, the properties of the molecule of the element. The properties of a quantity of hydrogen, it is said, are the properties of the molecules of hydrogen; when a molecule of hydrogen is separated into atoms, each atom is identical with every other atom; we cannot keep these atoms apart so as to examine their properties, for, according to the theory, they either at once combine with atoms of other elements which may be near them, or they coalesce in pairs to re-form molecules of hydrogen. We have good grounds for saying that the properties of an atom of hydrogen, or oxygen, or other element, are different from the properties of a molecule of hydrogen, or oxygen, or other element; but we cannot examine these grounds here.

The molecular and atomic theory has been developed chiefly for gases. The foundations of the theory are laid in physical and dynamical conceptions and reasonings which it would be out of place to discuss in this book. The theory has done much to advance physical and chemical science, and it is accepted, in some form or other, by all physicists and chemists. Nevertheless, it is not a generalisation of facts, like the laws of chemical combinations; it is a theory; it is an attempt, based on certain

assumptions, to bring into one point of view, and offer a consistent explanation of, a great many apparently diverse phenomena.

I do not attempt even to sketch the details of the theory, as that cannot be done without devoting much space to the subject, nor is it necessary for the special object I have in view in this book.

According to the molecular and atomic theory, the properties of an element or a compound, considered apart from other kinds of matter, are the properties of the molecules of that element or compound; when elements or compounds react chemically, in most cases their molecules are separated into parts, or atoms, and these parts combine in new arrangements to form the molecules of other elements or compounds. The atoms of the molecule of an element are all alike; the atoms of the molecule of a compound are of different kinds, as the molecule is composed of atoms of different elements. The term molecule is applied to elements and compounds; the term atom is applied to elements only. Thus we speak of the molecule of water as built up of two atoms of hydrogen and one atom of oxygen; we also say that the molecule of hydrogen is composed of two atoms of hydrogen, and the molecule of phosphorus is composed of four atoms of phosphorus.

I shall not discuss the methods by which the relative weights of molecules and atoms are determined; suffice it to say that hydrogen, the lightest known form of matter, is taken as the standard, that the weight of the atom of hydrogen is called one, and the weights of the atoms of the other elements are expressed in terms of that of hydrogen as unity; that, inasmuch as we have good evidence that the molecule of hydrogen is composed of two atoms,

the weight of the molecule of hydrogen is called two, and the weights of the molecules of other elements, and of compounds, are expressed in terms of that of hydrogen as twice unity.

The values of the atomic weights of the elements are the same as the values in actual use for the combining weights of the elements.

As a candle burns we can see things that are invisible, for one of the objects of science is to bring the invisible full into play; we see the molecules of the compounds of carbon and hydrogen that form the candle clashing with the molecules of oxygen in the air; we see the molecules shattered by their encounters: we see each atom of carbon thus set free combining with two atoms of oxygen, and we also see one atom of oxygen combining with two atoms of hydrogen; we see the new molecules of carbonic acid and water thus formed remaining intact, and swinging off in rhythmic motions through the atmosphere.

These molecules and atoms are perhaps the oldest things in the material universe. Myriads of years ago, the atom of carbon which has just been liberated from the molecular mesh of the burning candle was swinging, as it is swinging now, in union with two atoms of oxygen; for ages these atoms performed their rhythmic dance together; but a time came when the union was dissolved; the molecule of carbonic acid was absorbed by a plant, the carbon was separated from its companion atoms of oxygen, and was built up in association with other atoms of carbon and oxygen into the tissues of the growing plant. The plant was eaten by an animal, and the carbon atom passed into other combinations, until it was sent back to the atmosphere once more in union with its complement of atoms of oxygen.

This cycle of changes was repeated again and again, varied more than once by the molecule of carbonic acid being removed from the air into the sea, where it was absorbed by a living coral-insect, and by it built into the structure of a reef of coral. Or perhaps the atom of carbon was seized on by atoms of calcium and oxygen, and in such combination was locked up in limestone or marble. For many ages the carbon atom was imprisoned in union with atoms of hydrogen and oxygen in a large tree; the tree fell, and was buried by the accumulation of soil; and then began the gradual elimination of most of the oxygen, and some of the hydrogen, until the companions of the atom of carbon were a few atoms of hydrogen only.

Not many years ago, men dug up the lump of coal of which our atom of carbon formed a part, and heated it in a retort, when the carbon, still in combination with hydrogen, was removed from its resting-place to form part of a mass of paraffin. This paraffin was fashioned into candles, and from one of these, we have sent the atom of carbon, now in conjunction with oxygen, to renew the never ending round of change.

CHAPTER VI.

THE CHEMICAL PROPERTIES OF ELEMENTS AND COMPOUNDS.

WHEN a candle, a gas-jet, or a coal fire burns, chemical changes take place ; and these changes consist in reactions between elements and compounds, wherein compounds are separated into their constituent elements, and these elements are re-arranged in new compounds. These changes are similar to all other chemical changes ; in studying these changes we inquire into the compositions and properties of compounds, the properties of elements, and the changes in the forms and distribution of energy that accompany changes in the compositions and properties of the reacting bodies.

We have already looked to the compositions of compounds, and to the changes in the forms and distribution of energy that accompany changes of composition ; we must now endeavour to gain some insight into the properties of elements and compounds, and the connexions between these and the compositions of compounds.

In experiments 25 and 26 (pp. 50, 51), we found that carbonic acid gas was given off when muriatic acid or spirits of salt was poured on to chalk (or whitening). Muriatic acid is a liquid with an intensely sour and irritating taste, which corrodes and discolours the skin, and, as is commonly said, "burns" holes in cloth. Oil of vitrol is another fairly common liquid which, like muriatic acid, is

very sour and very corrosive.* Let us try the effect of pouring oil of vitriol on to chalk.

To examine the reaction of oil of vitriol with chalk.

Experiment 36.—Arrange the apparatus described in experiment 4, and shown in Fig. 4 (p. 7). Place a layer of powdered chalk in the flask, cover it with water, and pour a little oil of vitriol, diluted with five or six times its bulk of water,† down the funnel tube. Collect three small bottlefuls of the gas which comes off (*compare* experiment 4), and test its behaviour towards a lighted taper and a little lime-water; the gas puts out the lighted taper, and forms a white solid in the lime-water. Light a small candle, and invert the third bottle of the gas over, but a little distance above, the candle; the candle flame goes out; hence, the gas is considerably heavier than air. The gas is evidently carbonic acid.

The same gas is produced, then, by the action of oil of vitriol diluted with water on chalk as is given off when muriatic acid reacts with chalk. The gas is carbonic acid.

Vinegar is a sour-tasting liquid, somewhat resembling muriatic acid and oil of vitriol in its properties, but less sour and much less corrosive than these liquids. If vinegar is concentrated by heating steam is given off, and the liquid which remains in the vessel becomes more and more acidic, that is, sourer and more corrosive, until at last a pungent and burning liquid is obtained. This liquid is called *acetic acid*.

* Both these liquids are poisonous and dangerous to handle; great care must be used in working with them.

† The oil of vitriol should be diluted by pouring it very slowly into water which is kept stirred; do not pour the water into the oil of vitriol. Much heat is produced in the process. Use a thin beaker or flask, and stand it in a dish, in case it should break.

To examine the reaction of acetic acid with chalk.

Experiment 37.—Repeat the preceding experiment, but use acetic acid in place of diluted oil of vitriol. A gas is given off, and this gas has the properties of carbonic acid.

The same gas, carbonic acid, is produced by the action of acetic acid on chalk as is formed when chalk reacts with muriatic acid or with diluted oil of vitriol.

Aqua fortis, or nitric acid, is a very sour and very corrosive liquid.

To examine the reaction of nitric acid with chalk.

Experiment 38.—Repeat experiment 36, but pour some nitric acid * diluted with three or four times its bulk of water, on to the powdered chalk. Prove that the gas given off is carbonic acid.

When muriatic acid, nitric acid, oil of vitriol, or acetic acid, is poured on to powdered chalk, in each case a chemical action occurs, and in each case carbonic acid gas is given off.

These four liquids have therefore certain common properties ; they are all sour, they all more or less corrode skin, cloth, wool, &c., and they all react with chalk to give off carbonic acid gas. Let us find out whether these liquids have any other properties in common.

To examine the reaction of muriatic acid with iron and with zinc.

Experiment 39.—Arrange two apparatuses like that used in experiments 36, 37, and 38 ; but let the end of each delivery tube

* Do not let the nitric acid be spilt on to your hands or clothes ; it is very corrosive, and rapidly discolours and destroys the skin ; it is also very poisonous.

dip under water in a trough; put some iron filings in one flask, and some zinc clippings in the other; cover the solids with water, and pour a little muriatic acid into each flask. Gas is soon given off in both cases; collect two small bottlefuls of the gas coming from each flask, by filling the bottles with water, inverting them in the trough, and allowing the gas to bubble up into them (compare experiment 12, p. 21); before collecting the gas, allow the action to proceed for five or ten minutes, to make sure that all air is driven out of the apparatus. Bring a lighted taper to the mouth of one bottle of each pair, the bottle being held mouth downwards; the gas burns with a scarcely perceptible flame. Place the other pair of bottles, mouths upward, on the table, and after a minute or so bring a lighted taper to each; the gases have escaped. Hence the gas produced in these reactions is hydrogen. The experiment may be repeated, using diluted oil of vitriol in place of muriatic acid, and repeated again with acetic acid in place of oil of vitriol. In each case a reaction occurs—the reaction with acetic acid is very slow—and hydrogen is given off.

Hence muriatic acid, oil of vitriol, and acetic acid react with iron and zinc, and one of the products of the reactions is hydrogen.

**To examine the reaction of nitric acid with iron
and with zinc.**

Experiment 40.—Repeat the preceding experiment, but pour diluted nitric acid on to the iron and zinc in the flasks. A reddish gas is given off. Collect this gas in the usual way over water; the gas which collects in the bottles is colourless; but on removing the bottles from the trough the reddish colour is reproduced.

Hence nitric acid reacts with iron and zinc; a gas is given off, but that gas is not hydrogen.

These four liquids—muriatic acid, oil of vitriol, acetic acid, and nitric acid—behave in a similar, but not identical, way with zinc and iron.

In experiment 17 (p. 31) iron filings were allowed to absorb and combine with oxygen, the product was a compound of iron and oxygen; in experiment 18 (p. 33) zinc was caused to combine with oxygen by strongly heating the metal in air.

Let us now examine the reactions of the four liquids we are studying with oxide of iron and oxide of zinc (or burnt iron and burnt zinc), respectively.

To examine the reactions of muriatic acid, oil of vitriol, nitric acid, and acetic acid, with oxide of iron, and with oxide of zinc.

Experiment 41.—Warm some diluted muriatic acid, some diluted oil of vitriol, some diluted nitric acid, and some slightly diluted acetic acid, in four fair-sized porcelain basins. Add to each warm liquid red oxide of iron (or iron-rust) little by little, stirring well after each addition, and waiting until all is dissolved before adding more. Notice that no gas is given off during the solution. Continue to add the oxide of iron until a little remains undissolved in each basin after warming for some time; then pour a little water, not much, into each basin; arrange four funnels with a clean filter paper in each,* and beneath each place a clean basin. Pour the liquids through these funnels, and thus separate the liquids from the small quantities of undissolved oxide of iron. Notice that the liquids which run through the filters are slightly coloured. Place the four basins over *low* flames, and continue to evaporate, until a drop of liquid, taken out on a glass rod, leaves a slight solid deposit on the end of the rod after blowing on the liquid for a short time, and so causing it to evaporate quickly. When this

* Get circular filter papers; fold a paper down the centre so that a half circle is formed, then bring the two horns of the half circle together so as to produce a quadrant of a circle; place the point of the folded paper in the funnel, and open out the paper and press it against the sides of the funnel.

stage is reached remove the lamps from beneath the basins, and allow these to cool. As the liquids get cold, a solid substance forms in each ; if no solids form you must evaporate the liquids a *little* more, over *low* flames. When a fair quantity of solid has formed in each basin pour off the liquids into clean vessels (do not throw these liquids away), and examine the solid substances that remain.

Should you fail to get more than a very little solid in any case, evaporate the liquid poured off from the small quantity of solid till it becomes slightly thickish, and allow it to cool ; more solid will then form. It will probably be necessary to evaporate the solution of oxide of iron in muriatic acid until most of the liquid is driven off in order to obtain any solid substance.

Remove a little of each solid from the basin, by means of a glass rod, press it between filter paper, or blotting paper, until it is fairly dry, and then put it into water ; the solids dissolve, more or less easily, in water. Place a little oxide of iron in water ; it does not dissolve, even on heating and adding much water.

The solids obtained by dissolving oxide of iron in these four acid liquids are evidently different from the oxide of iron used ; and the solids are unmistakeably very different from the muriatic acid, oil of vitriol, nitric acid, or acetic acid, wherein you dissolved the oxide of iron.

Examine the liquids poured off from the four solids which formed on evaporating the solutions of oxide of iron in the four acid liquids. Taste a *very small* drop of each ; place a little of each on the skin of the hand ; place a small piece of cloth in each liquid, and allow it to remain for some time. The liquids are not sour, nor do they discolour or act on the skin, nor corrode the piece of cloth. Therefore the liquids are not the original acid liquids which were poured on to the oxide of iron.

Now repeat this experiment, but use oxide of zinc * (or burnt

* As ordinary oxide of zinc sometimes contains a compound of this oxide with carbonic acid, the oxide employed should be spread out in a thin basin, and strongly heated, with frequent stirring, for half an hour, before it is used ; the oxide should be used immediately it has become cold,

zinc) in place of oxide of iron. The oxide dissolves; no gas is given off; a white solid is obtained on evaporating each liquid, after it has dissolved as much oxide of zinc as it can and the excess of the oxide has been removed by filtration; all the solids are easily soluble in water, after pressing between filter paper; they are, therefore, different from the oxide of zinc used, which is not dissolved by water; the liquids poured off from the solids are not sour, nor do they corrode the skin or a piece of cloth; they are, therefore, different from the acid liquids in which the oxide of zinc was dissolved.

The results of this experiment show that muriatic acid, oil of vitriol, nitric acid, and acetic acid, all react with oxide of zinc, and with oxide of iron; that these acid liquids dissolve the two oxides without giving off any gas; and that on evaporating the solutions solids are obtained which differ in properties from the oxide of iron, or the oxide of zinc, and also from the acid liquids, used to produce the solids; and that the liquids poured off from these solids differ in properties from the acids used in their production.

A fair inference from these results is that each solid is composed of both the oxide and the acid used in its formation.

When iron and zinc dissolved in the four acid liquids whose properties we are studying gas was given off (experiments 39 and 40); what became of the iron and zinc?

To examine the reaction of the four acids used in last experiment with iron and with zinc.

Experiment 42.—Repeat experiment 41, but use iron filings in place of iron oxide, and zinc clippings in place of zinc oxide.

The metals dissolve; hydrogen is given off in three cases, and a reddish gas appears during the solution of the metals in nitric acid (*see* experiments 39 and 40); on evaporation, solids are obtained which are certainly not the original iron and zinc, and which resemble the solids obtained by dissolving oxides of iron and zinc in the same acid liquids. If the acids have been saturated with iron or zinc—that is, if the metal has been added until a little remains undissolved—it will be found that the liquids poured off from the solids formed on evaporation are different from the original acid liquids (*compare* experiment 41).

The four acid liquids then dissolve iron and zinc with the evolution of a gas, which is hydrogen in three cases, and the formation of solid substances which resemble, but are not therefore the same as, the solids produced by dissolving the oxides of iron and zinc in the same acid liquids. As neither the properties of the metals, nor the properties of the acid liquids, used, are recognisable in the liquids poured off from the solids, it is a fair inference to conclude, provisionally, that each solid is composed of both the metal and the acid used in its formation.

The conclusion drawn from the results of experiments 41 and 42 as probably correct, that each solid formed in these experiments is composed of the metal and the acid, or the metallic oxide and the acid, employed in its formation, is confirmed, with certain modifications, by the results of careful quantitative analyses of all the substances which take part in these chemical changes.

The four acid liquids, muriatic acid, oil of vitriol, acetic acid, and nitric acid, seem to react in a very similar way with iron, or zinc, and in a very similar way with oxide of iron, or oxide of zinc. These four liquids may be put

into the same class as regards their properties, and may be called *acids*.

Let us now examine the liquids that are formed when potash and soda are dissolved in water.

To examine the reactions of caustic soda and caustic potash with iron, zinc, oxide of iron and of zinc, and chalk.

Experiment 43.—Dissolve about 2 oz. (60 grams) of caustic potash in about a pint (600 c.c.) of water, and about the same weight of caustic soda in about the same volume of water. Pour some of each solution on to (1) iron filings, (2) zinc clippings, (3) iron oxide, (4) zinc oxide, and (5) powdered chalk; no visible action occurs in any case. Now heat the liquids; still no visible action occurs.

The properties of solutions in water of caustic potash and caustic soda are then very different from the properties of the acid liquids examined in the preceding experiments.

To examine the properties of caustic soda and caustic potash.

Experiment 44.—Make solutions in water of caustic soda and caustic potash, as directed in experiment 43. Notice that the liquids affect the skin, and are rather soapy and irritating to the touch. Pour some of each solution on to a little cotton wool, and macerate the wool in the liquid by means of a pestle; the wool is slightly corroded.

Fill a large test tube with carbonic acid gas (*see* experiment 4, p. 7); when the tube is quite full of the gas—that is, when a lighted taper is extinguished when brought to the mouth of the tube—*quickly* pour the caustic potash solution into the tube so as to fill it to about one-fourth; *at once* cover the mouth of the tube with the thumb, and shake vigorously. The fact that the

thumb is forced tightly against the tube by the pressure of the air shows that the gas in the tube has been absorbed by the potash solution. To confirm this result, bring the mouth of the tube, still closed by the thumb, under water, and withdraw the thumb; water rushes into and partly fills the tube.

Repeat this part of the experiment, using caustic soda in place of potash; the result is the same in both cases.

Solutions of caustic potash and soda are thus seen to have certain characteristic properties, and to be different from acid liquids.

To contrast caustic potash and caustic soda with acids.

Experiment 45.—To a little of each of the solutions of potash and soda prepared in experiment 44, add a few drops of litmus-solution;* the litmus becomes deep blue. To each solution add a few drops of an aqueous solution of turmeric; the yellow liquid becomes brownish red. To a few drops of solutions in water of muriatic acid, oil of vitriol, nitric acid, and acetic acid, separately, add a little litmus-solution, and a little turmeric solution; the litmus becomes red, and the turmeric remains yellow.

This experiment brings out a further difference between the properties of soda and potash, on the one hand, and the properties of muriatic acid, nitric acid, acetic acid, and oil of vitriol, on the other hand.

Now let us try to find out something about the change which occurs when potash or soda is added to one of the acid liquids we have been examining.

To neutralise oil of vitriol by caustic potash and examine the liquid formed, and the solid got by evaporating this liquid.

Experiment 46.—Place about $\frac{1}{2}$ a fluid oz. (about 15 c.c.)

* Litmus-solution is made by boiling litmus in water, allowing to settle, and filtering. Turmeric-solution is made in a similar way.

of oil of vitriol in a flask ; add a pint (600 c.c.) of water, and mix thoroughly ; measure off, *as accurately as you can*, $\frac{1}{4}$ a pint (150 c.c.) of this solution, pour it into a fair-sized porcelain basin, and add about 10 drops of litmus-solution. Dissolve about 4 oz. (120 grams) potash in a pint (600 c.c.) of water, and *shake the solution so that it is uniform throughout*. Pour the potash solution, *very slowly*, into the diluted oil of vitriol in the basin, stirring constantly with a glass rod, until the red colour of the acid liquid *just changes to blue*. Now measure the volume of the potash solution that remains. You thus find the volume of your potash solution that is required to change the colour of the acid liquid reddened by litmus, to the blue colour which you know to be produced in litmus by potash.

Repeat this part of the experiment, again using $\frac{1}{4}$ pint (150 c.c.) of the solution of oil of vitriol, pouring in *slowly* the volume of potash solution which you know will be nearly enough to effect the change of colour, and finishing the experiment by adding the potash solution drop by drop.

Now place $\frac{1}{4}$ a pint (150 c.c.) of the same solution of oil of vitriol in a basin, measuring it as accurately as you can ; do not add any litmus ; and then add exactly that volume of your potash solution which you have found to be needed to change the colour of litmus in $\frac{1}{4}$ a pint of the acid liquid to pale blue. Boil down this liquid over rather a low flame, until a drop taken out on a rod leaves a solid residue when it evaporates, (*compare* directions in experiment 41, p. 129) ; then turn out the lamp and let the basin and its contents cool. A white solid separates from the liquid, as the latter cools ; if no solid appears, evaporate the liquid *a little more*, and repeat this treatment, if necessary, until solid separates from the cooling or cold liquid.

Pour off the liquid from the solid ; dry the solid by pressing it between filter or blotting paper ; dissolve the solid in as small a quantity of water as possible, in a clean basin ; evaporate this solution till solid separates on cooling ; pour off the liquid, and dry the solid as before.

Dissolve the solid thus obtained in a little water ; to a few

drops of the solution add a few drops of blue litmus-solution, no change of colour takes place; to another very small quantity of the solution add a few drops of litmus which has been reddened by *one* drop of *very diluted* oil of vitriol, no change of colour takes place; hence an aqueous solution of the solid does not affect the colour of litmus-solution.

Pour a little of the solution of the solid on to iron filings, and warm; pour a little on to oxide of iron, and warm; pour a little on to powdered chalk, and warm; no visible action occurs in any case. Hence the solution of the solid does not react with iron, iron oxide, or chalk, as oil of vitriol does.

Completely fill a large test-tube with carbonic acid gas, close the mouth of the tube with the thumb, quickly pour in a little of the solution of the solid, close the tube and shake vigorously, bring the tube mouth downwards under water, and withdraw the thumb; the water does not rise in the tube; hence a solution of the solid does not absorb carbonic acid gas, as potash does.

Place some of the solution of the solid on the hand; and macerate a piece of cotton-wool in another portion of the solution. The skin is not affected, nor is the wool in any way corroded.

The results of this experiment show that the substance which is produced by adding potash to oil of vitriol until the colour of litmus is not affected by the mixture, possesses the properties neither of the acid nor of the potash by the interaction of which it has been produced.

The properties of the constituents—oil of vitriol and potash—are merged in the properties of the substance formed by their interaction.

Oil of vitriol or sulphuric acid, *aqua fortis* or nitric acid, *spirits of salt* or muriatic acid (it is also called hydrochloric acid), and concentrated *vinegar* or acetic acid, are representatives of the class of compounds called ACIDS.

Potash and soda are representatives of the class of compounds called ALKALIS.

Potassium sulphate, which is the solid formed by adding potash to sulphuric acid, is a representative of the class of compounds called SALTS.

If soda solution is added to sulphuric acid till the liquid does not affect the colour of litmus, and the liquid is evaporated, a salt, termed *sodium sulphate*, is obtained, and this salt resembles potassium sulphate in its properties.

By similar reactions, salts can be obtained by adding potash, or soda, to nitric acid, hydrochloric acid, and acetic acid; these salts are called *potassium* (or *sodium*) *nitrate*, *chloride*, and *acetate*, respectively. They all closely resemble potassium sulphate in their properties.

In these classes of bodies—acids, alkalis, and salts—is comprised a very great number of compounds; these compounds are of great importance both in pure and in applied chemistry.

Among the acids, besides those we have been studying, may be mentioned *phosphoric acid*, *sulphurous acid*, *hydrobromic* and *hydriodic acids*, *oxalic*, *lactic*, *benzoic*, *salicylic*, and *picric acid*, *arsenic acid*, *nitrous acid*, and *boric acid*. *Ammonia*, *soda*, *potash*, and *slaked lime*, are the four most important alkalis. A vast number of salts exists; we have *silicates of aluminium calcium* and *magnesium*, the chief salts in clay; *sulphate of iron* or green vitriol, *sulphate of copper* or blue vitriol, *sodium chloride* or common salt, *phosphate of calcium*—the chief salt found in bones—and a host of others.

The acids differ considerably in their properties, but

they all react similarly, although not identically, to those four we have examined, with litmus, iron, iron oxide, zinc, zinc oxide, chalk, and potash or soda. The alkalis react similarly to potash, with litmus, carbonic acid, and with acids. The salts, as a class, do not affect the colour of litmus, do not corrode animal or vegetable matter, and do not act like acids, or alkalis, towards iron, zinc, oxides of iron and zinc, or chalk.

The salts are formed by the interaction of acids with alkalis or with compounds which more or less resemble alkalis. The properties of the reacting bodies are merged in those of the salts formed by their interactions.

Why are acids acidic, and why are alkalis alkaline?

Let us attempt to find the outlines of an answer to this question.

Acids are acidic, said some of the alchemists, because they contain a "principle of acidity," and alkalis are alkaline because they contain a "principle of alkalinity"; others said that acids contain the "primordial acid," more or less mixed with earthy matter; and others averred that alkalis contain the "matter of fire."

It is very difficult to criticise these alchemical explanations; we cannot now put ourselves into the mental condition which accepted the assertion of the presence of a "principle of acidity," or a "principle of alkalinity," or a "primordial acid," as a real explanation of the properties of certain bodies which resembled one another. In science we have left behind the time when properties were explained by insisting on the presence of an undefined, partly material partly non-material something, which was supposed to be made real by being called a

"principle." The assertion of the presence of a common "principle," or a common "primordial acid," may have seemed a real explanation to the alchemists; to us it is no explanation at all. We know that the alchemical explanation was not productive of accurate knowledge; it was not a science-producing explanation; until it was abandoned, very little if any advance was made in the accurate study of the question which the explanation was supposed to answer.

The great founder of the science of chemistry, Lavoisier, put the question—why are acids acidic?—into the form in which it can be answered by an appeal to experiment. He asked; What are the compositions of those compounds which have the common properties that we express by the term acidic? Have these compounds anything in common in their composition?

The answer given by Lavoisier remains embodied in the name he gave to the gas that supports combustion; the word *oxygen*, acid-producer, is Lavoisier's reply to the question—why are the acids acidic? The element that is present in the air and supports the burning of bodies that burn in air is the acid-producing element, according to Lavoisier; in other words, all acids contain oxygen; the properties summed up in the term acidic are connected with the presence of oxygen in compounds.

Many acids have been prepared and analysed since the time of Lavoisier; we now know that although most acids contain oxygen, all do not. The examination of the compositions of acids has shown that all compounds which resemble oil of vitriol, aqua fortis, spirits of salt, or vinegar in their properties, are compounds of hydrogen

with one, two, or more other elements. Experiments have also proved that all compounds of hydrogen are not acidic—for instance, potash and soda, the typical alkalis, are compounds of hydrogen. And finally, the results of the analyses of many hundreds of acids have taught us that compounds which are acidic are composed of hydrogen united with large quantities (relatively to the quantity of hydrogen) of elements which more or less closely resemble oxygen in their properties, and which may be called *oxygen-like elements*. When a compound is composed of hydrogen, oxygen, and one or more of the oxygen-like elements, that compound is generally like oil of vitriol, muriatic acid, or nitric acid in its properties—it is generally acidic; and this is especially the case when the quantity of the oxygen-like elements, or of the oxygen, or of both, is large compared with the quantity of hydrogen in the compound.

The commoner oxygen-like elements are sulphur, phosphorus, chlorine, bromine, iodine, and silicon; nitrogen and carbon must also be classed among the elements which, in some respects, are like oxygen. Iron, lead, copper, tin, silver, and the other metals, may be put together and called the *hydrogen-like elements*; although the metals are very different from hydrogen in their physical properties—for instance, hardness, colour, relative density, tenacity and ductility—nevertheless, in their chemical properties they resemble hydrogen much more than they are like oxygen.

Compounds of hydrogen with the metals or hydrogen-like elements are not acids; compounds of hydrogen with both hydrogen-like and oxygen-like elements are not

generally acidic, unless there is a very large quantity of the oxygen-like element present, compared with the quantity of hydrogen and hydrogen-like element in the compound.

The foregoing statements imply that the compositions and properties of a very great number of compounds have been ascertained; the statements also carry with them but little accurate knowledge unless a definite meaning can be given to the terms oxygen-like elements and hydrogen-like elements.

It is impossible to make an examination of these terms now; such an inquiry can be undertaken with profit only by devoting much time and attention to the study of chemistry.

A word or two must suffice.

When an electric current is passed through a mixture of water with a little oil of vitriol hydrogen is given off in contact with one of the plates of platinum immersed in the liquid, and oxygen appears in contact with the other plate of platinum (*compare* experiment 11, p. 18). When a compound of an oxygen-like and a hydrogen-like element—for instance, copper chloride, the composition of which is expressed by the formula CuCl_2 —is decomposed into its elements by an electric current, the hydrogen-like element (copper) is separated at the same plate as that whereat hydrogen appears during the electrolysis (splitting up by electricity) of water containing oil of vitriol, and the oxygen-like element (chlorine) appears at the same plate as that whereat oxygen is given off during the electrolysis of acidified water.

When water is decomposed by reacting with a hydrogen-

like element—for instance, by heating with hot iron as in experiment 33, p. 79—the oxygen of the water combines with the hydrogen-like element, and hydrogen is given off from the water uncombined with other elements; when water is decomposed by reacting with an oxygen-like element—for instance, when a mixture of steam and chlorine is passed through a very hot porcelain tube—the hydrogen of the water combines with the oxygen-like element, and the oxygen of the water is given off uncombined with other elements.

Many compounds of hydrogen-like elements with oxygen dissolve, more or less easily, in water, and the solutions contain compounds which are like potash and soda in their properties—that is, which are alkaline; many compounds of oxygen-like elements with oxygen dissolve, more or less easily, in water, and the solutions contain compounds which are like nitric acid, or acetic acid, in their properties—that is, which are acidic.

These statements, which must be accepted by the student without personal verification at present, may enable one to form some notion of what is meant by the terms *hydrogen-like elements* and *oxygen-like elements*.

Acidic compounds, then, are composed of hydrogen united with comparatively large quantities of oxygen-like elements, and one of the oxygen-like elements in acids is very frequently oxygen itself. Alkaline compounds are composed of hydrogen united with comparatively large quantities of hydrogen-like elements and also with oxygen.

The following formulæ show the compositions of a few acidic, and a few alkaline, compounds:—

ACIDIC COMPOUNDS.

Name.	Formula.	Composition			
		in combining weights of elements.		in parts of each element per 100 of compound.	
		Hydrogen.	Oxygen-like Element.	Hydrogen.	Oxygen-like Element.
Hydrochloric Acid	HCl	1 c. wt. hydrogen + 1 c. wt. chlorine	...	2.7 hydrogen + 97.3 chlorine	...
Sulphuric	H ₂ SO ₄	" + 1 "	sulphur	" + 32.7 sulphur	+ 65.4 oxygen
Nitric	HNO ₃	" + 1 "	nitrogen	" + 22.2 nitrogen	+ 76.2 "
Chloric	HClO ₃	" + 1 "	chlorine	" + 42 chlorine	+ 56.8 "
Periodic	HIO ₄	" + 1 "	iodine	" + 66.1 iodine	+ 33.3 "
Phosphoric	H ₃ PO ₄	" + 1 "	phosphorus	" + 31.6 phosphorus	+ 65.3 "
Silicic	H ₂ SiO ₃	" + 1 "	silicon	" + 35 silicon	+ 61.5 "
Acetic	H ₄ C ₂ O ₄	" + 2 "	carbon	" + 40 carbon	+ 53.5 "
Oxalic	H ₂ C ₂ O ₄	" + 2 "	" "	" + 26.6 "	+ 71.1 "

ALKALINE COMPOUNDS.

Name.	Formula.	Composition			
		in combining weights of elements.		in parts of each element per 100 of compound.	
		Hydrogen.	Oxygen-like Element.	Hydrogen.	Oxygen-like Element.
Potash	HOK	1 c. wt. hydrogen + 1 c. wt. potassium + 1 c. wt. oxygen	...	1.8 hydrogen + 69.6 potassium + 28.6 oxygen	...
Soda	HONa	" + 1 "	sodium	" + 57.5 sodium	+ 40 "
Slaked lime	H ₂ O ₂ Ca	" + 1 "	calcium	" + 54 calcium	+ 43.2 "
Baryta	H ₂ O ₂ Ba	" + 1 "	barium	" + 80.1 barium	+ 18.7 "
Strontia	H ₂ O ₂ Sr	" + 1 "	strontium	" + 71.9 strontium	+ 26.4 "

These examples suffice to show that the acidic compounds mentioned contain very large quantities of oxygen-like elements, relatively to the hydrogen in them, oxygen itself being included in the class of oxygen-like elements; and that the alkaline compounds mentioned contain relatively large quantities—at least 50 per cent. by weight—of the hydrogen-like elements which enter into their composition.

The composition of the acidic compounds may be represented by the general formula H_xOx_y , and that of the alkaline compounds by the general formula $H_xHyd_yO_z$, where H_x stands for x combining weights of hydrogen; Ox_y stands for y combining weights of an oxygen-like element, including oxygen itself; Hyd_y stands for y combining weights of a hydrogen-like element; and O_z for z combining weights of oxygen; in these formulae y has generally a fairly large value.

Salts are formed when alkaline compounds react with acidic compounds. The properties of salts are different from those of either of the compounds that have reacted to form them; salts are neither alkaline nor acidic. Can any generalisation be made regarding the composition of salts, and regarding the connexions between their compositions and those of the alkaline and acidic compounds by the interaction of which the salts are produced?

The simplest way to answer this question will be to tabulate the compositions of some of the salts formed by the interaction of the acidic and alkaline compounds represented in the foregoing tables.

ACIDS, ALKALIS, AND SALTS.

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I.	II.	III.		
<i>Acidic Compound.</i>	<i>Alkaline Compound.</i>	<i>Salt</i>		
		formed by interaction of acidic and alkaline compounds in cols. I. and II.		
		Hyd.-like Elements.	Oxy.-like Elements.	Name of Salt.
HCl hydrochloric acid	HOK potash	K	Cl	potassium chloride
HNO ₃ nitric	HOK	K	NO ₃	potassium nitrate
H ₂ SO ₄ sulphuric	HONa soda	Na ₂	SO ₄	sodium sulphate
H ₃ PO ₄ phosphoric	HONa	Na ₃	PO ₄	sodium phosphate
H ₄ C ₂ O ₂ acetic	HONa	NaH ₃	C ₂ O ₂	sodium acetate
H ₄ C ₂ O ₂	HOK	KH ₃	C ₂ O ₂	potassium acetate
H ₂ C ₂ O ₄ oxalic	HOK	K ₂	C ₂ O ₄	potassium oxalate
HCl	H ₂ O ₂ Ca slaked lime	Ca	Cl ₂	calcium chloride
HNO ₃	H ₂ O ₂ Ca	Ca	2NO ₃	calcium nitrate
H ₂ SO ₄	H ₂ O ₂ Ba baryta	Ba	SO ₄	barium sulphate
H ₂ C ₂ O ₄	H ₂ O ₂ Sr strontia	Sr	C ₂ O ₄	strontium oxalate
H ₄ C ₂ O ₂	H ₂ O ₂ Ca	Ca2H ₃	2C ₂ O ₂	calcium acetate
H ₄ C ₂ O ₂	H ₂ O ₂ Ba	Ba2H ₃	2C ₂ O ₂	barium acetate
H ₃ PO ₄	H ₂ O ₂ Sr	Sr ₂	3PO ₄	strontium phosphate

A careful consideration of the compositions of these compounds shows that the salt is always a compound of the oxygen-like element or elements of the acid with the hydrogen-like element of the alkaline compound; and that in a few cases the salt contains hydrogen in addition to the hydrogen-like element of the alkali and the oxygen-like elements of the acid. This statement may be expressed in other words, by saying that the salt is formed by the hydrogen-like element of the alkaline compound taking the place of the hydrogen—generally of all the hydrogen, but sometimes of only a portion of the hydrogen—of the acidic compound.

The change of properties that is implied when the word *salt* is contrasted with the word *acid* is accompanied by a change of composition, which consists in the removal

of hydrogen from an acid, and the combination of the elements of the acid that then remain with the hydrogen-like element of an alkaline compound. A little reflection will show that this generalisation could not have been reached without the quantitative examination of a great many compounds; that is, without making quantitative analyses of the compositions, and quantitative studies of the properties, of many compounds. A thorough grasp of all that the generalisation implies can be attained only by making a series of such quantitative studies of representative acids, alkaline compounds, and salts.

The questions—Why are acids acidic? Why are alkalis alkaline?—have not been answered; because the questions are not the kind of questions to which scientific answers—that is, answers which bring exact knowledge—can be found. The answer that chemical investigation gives to these questions is:—the properties connoted by the term *acidic* accompany a certain definite composition, and the properties connoted by the word *alkaline*, accompany another equally definite composition; acids are compounds of hydrogen with relatively large quantities of oxygen-like elements, alkaline bodies are compounds of hydrogen with oxygen and relatively large quantities of hydrogen-like elements; when acids and alkaline compounds interact salts are formed, and these salts are compounds of hydrogen-like elements with the oxygen-like elements of acids. To fully understand this answer means to make a detailed study of the greater number of the elements and their compounds; but such a study is out of the question here.

The investigation of the compositions and properties of acids, alkaline compounds, and salts, and of the changes of

composition and properties which attend the formation of salts by the interactions of acids with alkalis, is a representative instance of chemical study.

In the very slight sketch that has been given of the methods of conducting this examination, and of the results that have been obtained by the examination, attention has been paid to the chemical, rather than to the physical, properties of the compounds examined. We have not inquired whether the acids are liquids, solids, or gases; whether they are specifically heavy or light; whether they are coloured or colourless, or whether they melt easily or only at high temperatures; we have not asked whether alkaline compounds are like metals to the sight or the touch; whether they rather resemble water, or whether they differ in appearance from the substances commonly met with in every-day life; we have asked no questions regarding the appearance, colour, hardness, ductility, tenacity, sonorousness, smell, or taste of salts. We have confined our examination almost entirely to the chemical properties of the compounds. The chemical properties of a body are those which come within our cognisance when the body interacts with others, or when it undergoes a change of composition by the action of some form of energy upon it. Thus, one of the chemical properties of water is that water-gas is decomposed when it is passed over heated iron, with production of hydrogen, and oxygen which combines with the iron; another chemical property of water is that a mixture of water and oil of vitriol is decomposed by the electric current, with production of hydrogen and oxygen; and a third chemical property of water is that it is separated by the application of much heat into its elements; one of the chemical properties of

an acid is that it reacts with alkaline compounds to form salts.

The reaction of an acid with an alkaline compound is a chemical change ; this change, like all chemical changes, consists of three main parts :—(1) there is a change in the distribution of certain forms of matter ; (2) there is a change in the properties of the matter which suffers an alteration of form ; (3) there is a change in the form and distribution of the energy of the changing material system.

The reaction of an acid with an alkaline compound is attended with the appearance of heat ; the reaction could therefore be employed as a source of energy for doing mechanical work.

The acid and alkaline body may be regarded as fuel ; the change which occurs when these bodies interact may be likened to a process of burning ; the salt that is formed by the interaction may be compared with the ashes that remain when the burning is finished. Just as the ashes of a combustion can be unburned to the fuel which fed the burning, by doing work, under proper conditions, upon these ashes, so salts can be changed back to the acids and the alkaline compounds by the interaction of which they were formed, and this change is accomplished by doing work upon the salts, under certain definite conditions. To determine the conditions under which salts are transformed back to the acids and alkaline compounds which reacted to produce them is a task demanding many careful experiments, and is not to be undertaken without a considerable knowledge, gained by experiment, of the chemical properties of many individual salts, acids, and alkaline compounds.

The changes of composition that take place in the

formation of a salt from an acid and an alkali are stated in the language of the molecular and atomic theory somewhat as follows. The solution of the acid is regarded by the theory as containing a vast number of extremely minute, but not inconceivably minute, portions of matter, each of which has the properties of the acid, and all of which have the same properties and the same mass; these minute particles, or molecules, are pictured to us as composed of yet smaller particles, or atoms; the atoms are extremely small portions of the elements that compose the acid; the molecule is the collocation of these atoms into a group or building. The molecule of sulphuric acid, for instance, is represented as built up of two atoms of hydrogen in union with a single atom of sulphur and four atoms of oxygen; this group of atoms has its own properties, and these are different from those of any of the atoms which form the group.

The properties of the individual atoms are merged in those of the molecule, yet the properties of the molecule depend upon, although they are not the sum of, the properties, and the numbers, of the atoms that compose it. For instance, the properties of the molecules represented by the formulæ HNO_3 and HClO_3 are very different,—both, it is true, are the molecules of acids—although both contain a single atom of hydrogen and also three atoms of oxygen; the displacement of an atom of nitrogen by an atom of chlorine has effected a very marked change in the properties of the molecule. Again, the properties of the molecules represented by the formulæ H_2SO_3 and H_2SO_4 are distinctly different—both are acids which resemble one another in several respects—although the only difference in their composition is that the molecule of

one contains four atoms of oxygen, while the molecule of the other contains three.

The theory bids us picture to ourselves the solution of an alkaline compound as also containing a vast number of very small, but not inconceivably small, particles, each of which has the properties of the compound in solution, and all of which have the same properties and the same mass. We are to think of the molecules of the acid, and the molecules of the alkali, as moving rapidly among the molecules of the solvent, as at times colliding one against another, then rebounding, and moving off in straight lines. Now, let the solution of acid and alkali be mixed in the proper proportions, as was done in experiment 46. The theory tells us that an interchange of atoms occurs; the hydrogen-like atom of the molecule of the alkali exchanges places with the hydrogen atoms, or some of the hydrogen atoms, of the molecule of the acid; the result is two new molecules: one of the new molecules is composed of the oxygen-like atoms of the acid molecule united with the hydrogen-like atom of the molecule of the alkali—this is the molecule of the salt that is formed; the other new molecule is composed of the hydrogen atom, or atoms, which have been turned out of the molecule of the acid, combined with the oxygen and hydrogen atoms which remain of the molecule of the alkali—this new molecule is a molecule of water; for a salt is not the sole product of the reaction between an acid and an alkali, another product is water.

We have then to regard a molecule as a definite structure, built of a definite number of parts or atoms, and possessed of properties which are not the sum of the properties of the atoms, but are conditioned by the properties of the atoms,

and also by the numbers of the atoms, of each kind which are collected and held together to form the molecule.

The properties of hydrogen, according to the molecular and atomic theory, are the properties of the molecules of this element; but the properties of an atom of hydrogen existing in the molecule of a compound—for instance in nitric acid or in caustic potash—are different from the properties of the molecule of hydrogen; and moreover, within certain limits, these properties are conditioned by, and depend upon, the nature and the numbers of the other atoms which are combined with the atom of hydrogen in the molecules in question.

Hydrogen in nitric acid can be replaced by hydrogen-like elements—for instance by iron, copper, silver, lead, or mercury—by bringing the nitric acid into contact with a compound of one of these hydrogen-like elements with oxygen and hydrogen—that is, into contact with an alkaline compound; but hydrogen in caustic potash cannot be replaced, under similar conditions, by a hydrogen-like element.

The molecule must be regarded as a structure, having its own properties when considered as a whole, and having the properties of any one of its parts or atoms dependent on the nature of these atoms, and on the nature of the other atoms with which these are combined, and also on the numbers of the various atoms which together form the molecule.

This field of inquiry cannot be pursued here; it is very wide, very fruitful, and very fascinating. Suffice it to say that further study reveals the fact that two molecules that are composed of the same number of the same atoms may yet exhibit different properties. The accumulation of facts of this kind has forced chemists to recognise that the

properties of molecules are conditioned by a factor which is not either the nature, or the number, of the atoms that form the molecules. The only way we can represent the facts to our mind is by supposing that the third conditioning factor is the way in which the atoms, or the parts of the molecule, are arranged relatively to each other.

When we think over the reactions of the various bodies we have been studying, the question must arise—What is the cause of the interactions which occur between some definite kinds of matter, resulting in changes of composition, of properties, and of the form and distribution of energy? Why do not all elements and compounds react chemically? Why do some substances react at the ordinary temperature, and react instantaneously—for instance solutions of acids with solutions of alkalis—while other substances react only at high temperatures, and even then react but slowly—for instance candle-stuff with oxygen in the air? Can we connect the greater or less readiness of compounds to undergo chemical change with the compositions of these compounds, or with the greater or smaller quantities of energy that are associated with the different compositions?

In order that such inquiries as are suggested by these questions may be gathered together under a common name, it is customary to call the cause of chemical interactions, *chemical affinity*. Chemists do not yet know what chemical affinity is, although they are advancing towards this knowledge; they can, however, measure the effects of the unknown cause, they are able to compare the affinities of many different compounds, and thus they are approaching a solution of the problem of the cause of chemical action.

But here again, vast fields of investigation are opened which must be left by us untrodden.

To understand the occurrences that are included in the every-day process of burning a candle is to understand the whole of chemistry, and no small part of physics.

The main conclusions we have come to in our study of the burning candle, or gas-jet, or coal fire, are these:—

The process of burning is accompanied by the formation of substances which are quite unlike the substances that are burnt.

Besides the burning body, that is visible, there is another substance intimately concerned in the burning; that other substance is a constituent of the air wherein the combustion takes place.

Burning is accompanied by changes of composition and changes of properties, and both changes are perfectly definite.

In the changes which take place while a body burns there is no loss, and there is no gain, of matter; the total quantity of matter taking part in the process remains unaltered.

While the total mass of the changing system remains unchanged, the system loses the power of doing work; the ashes that remain cannot do what the unburnt substance could do. But the energy that is lost to the system undergoing combustion does not pass out of existence; it changes its form, and in changed forms it is taken up by other portions of matter which surround the burning body. The ashes may be unburnt to the original combustible substance by doing work upon them, under proper conditions.

Burning is a representative chemical change. In chemical changes substances are produced unlike those which react to produce them, and the new substances have different properties, and different compositions, from those of the substances which produced them; in chemical changes there is no loss or gain of matter, but there are alterations in the forms and distribution of matter, and there are also alterations in the forms and distribution of energy.

Attempts to represent the definite changes of composition that characterise chemical occurrences lead to the recognition of two classes of bodies, elements and compounds. The properties of every element and every compound are perfectly definite; compounds are composed of fixed quantities of elements; elements are those definite kinds of matter which have not been resolved into unlike portions.

The facts concerning the compositions of compounds, and the quantities of elements that combine to form compounds, are generalised in the three laws of chemical combination. These laws are accurate statements of what holds good in every chemical change. The laws are all included in the statement:—

The elements combine in the ratios of their combining weights, or of whole multiples of their combining weights.

On this statement is founded a consistent method of representing the compositions of compounds in terms of the numbers of combining weights of their constituent elements.

Compounds are classified both by their composition and their chemical properties—that is the properties exhibited when they react with other compounds or with elements.

Acids, alkalis, and salts are examples of three important classes of compounds.

It is possible to connect the properties connoted by the terms acid, alkali, and salt, with the compositions of the compounds which exhibit these properties, and to generalise the connexions between the properties and compositions of these three classes of bodies.

The molecular and atomic theory gives a fairly satisfactory picture of the mechanism whereby chemical changes are carried on. Chemical change consists, according to this theory, in interactions between minute portions of elements and compounds, which are called molecules, wherein these minute portions are separated into yet smaller parts, which are called atoms, and these atoms are re-arranged to form new molecules. The properties of the molecule of a compound—and these are the properties of any larger quantity of the compound—are represented by the theory as dependent on the nature and the number of the atoms which form the molecule, and upon a third condition, different from these, and which can be conceived only as the relative arrangement of the atoms.

The method whereby our results have been gained consists in making observations of natural occurrences, comparing these occurrences with others which seem to be like them, reasoning on the results of the observations and comparisons, performing experiments that are suggested by the conclusions drawn from the outcome of this reasoning, framing hypotheses to connect together the results of these experiments and represent them as the effects of a common cause, gauging the extent of the applicability and the measure of the fruitfulness of the hypotheses by making deductions therefrom, which can be, and are, tested by quantitative

experiments, and uniting the observations, comparisons, experiments, and hypotheses, by the connecting and sustaining bond of a general theory.

Chemistry stretches forth on two sides. Chemistry is the science which, as much as any other, touches our ordinary daily lives; the changes that we see taking place in spring and autumn, in summer and winter, are partly chemical; the changes wherein our food becomes bone, blood, muscle, nerve, and flesh, are partly chemical; many manufactures in which thousands of our fellow-citizens spend their working days are the applications of chemical processes and chemical principles. And chemistry also raises in our minds questions which thought cannot solve; she is concerned not only with the common round but also with the deepest problems of our intellectual life.

In every definite change of composition that happens is contained the whole science of chemistry. And much more besides; for there is no such thing in nature as a purely chemical change. We must turn our eyes aside from parts of the simplest natural event if we would see any picture of it with distinctness. But now and again it is well to seek the vision of the whole, although thereby we run some risk of loss in the clearness of the parts. The man of science and the poet are fellow-workers; both seek the vision that brings understanding, and the receding vision leads them both to new conceptions of beauty, of order, and of truth.

APPENDIX I.

Table of Names, Symbols, and Combining Weights (in round numbers) of the Elements. For meaning given to Combining Weight see p. 114.

Aluminium	27	Molybdenum	96
Antimony	120	Nickel	58·6
Arsenic	75	Niobium	94
Barium	137	Nitrogen	14
Beryllium	9	Osmium	191
Bismuth	208	Oxygen	16
Boron	11	Palladium	106
Bromine	80	Phosphorus	31
Cadmium	112	Platinum	194
Caesium	133	Potassium	39
Calcium	40	Rhodium	103
Carbon	12	Rubidium	85·4
Cerium	140	Ruthenium	101
Chlorine	35·5	Scandium	44
Chromium	52·2	Selenium	79
Cobalt	59	Silicon	28
Copper	63·2	Silver	108
Didymium	144	Sodium	23
Fluorine	19	Strontium	87
Gallium	66·9	Sulphur	32
Germanium	72·2	Tantalum	182
Gold	197	Tellurium	125
Hydrogen	1	Thallium	204
Indium	113·5	Thorium	232
Iodine	127	Tin	118
Iridium	192·5	Titanium	48
Iron	56	Tungsten	184
Lanthanum	139	Uranium	240
Lead	207	Vanadium	51
Lithium	7	Ytterbium	173
Magnesium	24	Yttrium	89
Manganese	55	Zinc	65
Mercury	200	Zirconium	90

APPENDIX II.

List of Apparatus and Materials needed for carrying out the Experiments described in this book.

NOTE A.

ALWAYS WORK WITH CLEAN APPARATUS; IF POSSIBLE, USE DISTILLED WATER.

NOTE B.

ALWAYS READ THE WHOLE OF THE DIRECTIONS GIVEN FOR CONDUCTING AN EXPERIMENT BEFORE BEGINNING THE EXPERIMENT.

LIST OF APPARATUS.

- A moderately good balance, such as Becker's No. 43. Some small shot.
- A battery of one or two Grove's cells, or three or four bichromate cells.
- Three earthenware, or glass, flat dishes; one about 10 or 12 in. diameter by 8 in. deep, one 9 in. diameter by 6 in. deep, and one 4 or 5 in. diameter by 2 in. deep.
- A large trough about 2 ft. deep is required for experiments 8 and 17; a deepish bath will serve.
- A large stoneware jar to hold about two gallons, with opening near the bottom (*see* figure 2, p. 5).
- Six thin glass jars for holding gases; about 12 to 15 in. high by 5 to 6 in. diameter. Glass plates to cover mouths of these jars.
- A fair sized bell jar; about 15 in. high by 6 in. diameter.
- One graduated jar holding one pint, or 600 c.c.; a smaller vessel with finer graduations is also desirable.
- Three or four moderate sized beakers; say 5 to 8 in. high.

- Six flasks, about 16 oz. capacity. Two small flasks, about $1\frac{1}{2}$ -2 oz. capacity. Caoutchouc corks with two holes to fit these flasks. One good sized round bottomed flask.
- Two funnel tubes, about 10 to 12 in. long.
- Three or four U-tubes, about 4 in. long; one U-tube about 2 in. long. Two funnels about 3 in. diameter.
- Piece of glass tubing, 14 to 16 in. long and 3 in. diameter; a piece of hard glass tubing about 12 in. long and $\frac{1}{2}$ in. diameter. Some glass tubing about $\frac{1}{4}$ in. diameter.
- About one dozen test tubes; a few larger test tubes; about half-a-dozen test tubes of hard glass.
- A piece of glass rod.
- A couple of similar ordinary lamp-chimneys.
- Two or three porcelain crucibles, about 1 in. deep; a couple of smaller crucibles. A pair of crucible tongs.
- About half-a-dozen porcelain basins, 4, 5 and 7 in. diameter.
- A couple of deflagrating spoons.
- A mortar and pestle.
- A drying cylinder, 7 or 8 in. high and $1\frac{1}{2}$ in. diameter (*see figure 11, p. 23*).
- A sharp triangular file; a rat's tail file, or a set of cork borers.
- A selection of about two or three dozen good corks from $\frac{3}{8}$ to $1\frac{1}{2}$ in. diameter.
- Caoutchouc tubing to connect glass tubes $\frac{1}{4}$ in. diameter.
- Two or three Bunsen lamps. A sand tray and some dry sand.
- Three or four good screw pinchcocks. A piece of cardboard.
- Three tripods, with gauze.
- Two clamps, to hold flasks, &c.
- Thermometer (not necessarily very delicate) to register to about 120° C.
- About a yard thin platinum wire; piece of platinum foil about 4 in. by 1 in.
- Three or four small candles; candlestick; extinguisher. Small oil lamp. Splints of thin wood. Some tapers. A little cotton wool. A few feet of thin covered copper wire; about 3 ft. stout copper wire.

LIST OF CHEMICALS.

Hydrochloric, Nitric, Sulphuric, and Acetic Acids.
Caustic potash and soda. Some pieces of *good* lime. Lime water.

Pieces of marble ; a little chalk, and some whitening. Copper sulphate. Calcium chloride, for drying purposes.

A very little silver nitrate.

A little litmus ; a little turmeric. A few pieces of charcoal.

Some *ferrum redactum*.

A piece of thin copper foil, about 12 in. by 2 or 3 in.

A little granulated tin and lead, and some zinc ; also zinc-dust. Iron filings.

A few pieces of phosphorus. Some pieces of sulphur.

Oxides of zinc and iron ; a little mercuric oxide and a little red lead.

A little potassium chlorate and manganese dioxide.

Distilled water.

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